AN ABSTRACT OF THE THESIS OF

Kristin A. Francis for the degree of Master of Science in Environmental Health and Occupational Safety Management presented on April 26, 2004.
Title: West Nile Virus Preparedness in Multnomah County: Efficacy, Benefits, and Limitations of Adulticide Use for Mosquito-Borne Disease.

Abstract approved:
Redacted for Privacy

Annette M. Rossignol

The objectives of this study were to provide a comprehensive review of the risks and benefits of using adulticides to reduce risk of mosquito-borne disease (particularly West Nile Virus) transmission to humans, as well as to decrease annoyance from nuisance mosquitoes. The study was designed with two major research components, including: 1) an extensive literature review to determine the efficacy of adulticide use, the adverse effects of adulticide use, the impact of mosquitoes on community livability, and the risks and benefits of pesticide use in controlling mosquitoes; and 2) interviews with selected vector districts in seven states to determine effective and ineffective practices in mosquito management. This study has demonstrated that an integrated mosquito management program may be beneficial in reducing risk of disease transmission and mosquito annoyance when performed *appropriately*. The contribution of adulticiding to reducing mosquito-borne disease transmission, however, is unknown. Research is needed to: 1) further assess the ecological and human impacts of adulticides using the dose and exposure rates realistic to an adulticide program; 2) gain an understanding of the human and ecological impacts of aggregate and cumulative exposures to pesticides, especially for special populations, such as children; and 3) determine the contribution of adulticiding in interrupting or reducing the enzootic amplification of arboviruses, as well as the transmission of WNV to humans.

West Nile Virus Preparedness in Multnomah County: Efficacy, Benefits, and Limitations of Adulticide Use for Mosquito-Borne Disease.

by
Kristin A. Francis

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Presented April 26, 2004.
Commencement June 2004

Master of Science thesis of Kristin A. Francis presented on April 26, 2004.

APPROVED:

Redacted for Privacy

Major Professor, representing Environmental Health and Occupational Safety Management

Redacted for Privacy

Chair of the Department of Public Health

Redacted for Privacy

Dean of Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Redacted for Privacy

Kristin A Francis, Author

ACKNOWLEDGEMENTS

The author expresses sincere appreciation to the National Pesticide Information Center for the use of their facts sheets, the Multnomah County Department of Vector and Nuisance Control for their assistance and encouragement, and the thesis committee at Oregon State University for their guidance and support.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

West Nile Virus Preparedness in Multnomah County: Efficacy, Benefits, and Limitations of Adulticide Use for Mosquito-Borne Disease.

Chapter 1-Introduction

In the United States, mosquito-borne diseases present a major concern for public health agencies. Rose (2001) reports that dengue, malaria, Eastern equine encephalitis (EEE), Western equine encephalitis (WEE), and St. Louis encephalitis (SLE) are among the diseases known to have caused severe illness and death in the United States in recent years. In Oregon, DeBess (2003) reports that WEE, SLE, and Showshoe hare all have been identified.

In addition, new mosquito-borne threats continue to emerge, including West Nile Virus (WNV)—an Old World Flavivirus transmitted by anthropophilic mosquitoes (Rose, 2001). WNV first appeared in the United States in New York in 1999, causing 62 cases of illness and seven deaths in humans (Rose, 2001). Since that time, the virus has survived winter conditions and subsequently spread westward across the continental United States. In 2002, there were 4156 laboratory confirmed cases of human WNV infection and 284 deaths in the United States (Sampathkumar, 2003). In 2003, there were 9377 reported cases of WNV-related illnesses and 244 deaths in the United States (CDC, 2004). Although the virus has not yet been found in Oregon, it is anticipated to arrive in 2004.

The objectives of this study are to provide a comprehensive review of the risks and benefits of using insecticides to reduce risk of mosquito-borne disease (particularly WNV) transmission to humans, as well as to decrease annoyance from nuisance mosquitoes. This study is performed in conjunction with the Health Department of Multnomah County, Oregon, to assist in preparing for the upcoming mosquito season this spring.

1.1 West Nile Virus Transmission Cycle. The Illinois Department of Public Health (2004) reports that WNV is amplified by continuous transmission between mosquito vectors and bird reservoir hosts. Competent bird reservoirs will sustain an infectious viremia for 1 to 4 days following exposure, after which these hosts develop immunity (IDPH, 2004). The transmission of WNV occurs when a mosquito bites an infected bird, ingesting virus along with its bloodmeal (Bren, 2003). The virus circulates and multiplies in the mosquito's blood for several days, finally penetrating the mosquito's salivary glands (IDHW, 2004).

After an extrinsic incubation period of 10 to 14 days, the infected mosquito can transmit WNV to humans and animals while taking its next bloodmeal (IDHW, 2004). A sufficient number of vectors must feed on an infectious host to ensure that some survive this extrinsic incubation period to feed again on a susceptible reservoir host (IDPH, 2004). While taking a bloodmeal from humans or other animals, the saliva and virus are injected from the mosquito into the host, where the virus is able to multiply and potentially cause illness (IDHW, 2004).

Nosal and Pellizzari (2003) report that different types of mosquitoes are responsible for risk of WNV transmission in human populations. First, amplification species, such as *Culex pipiens*, feed primarily on birds and transmit the virus to other birds, creating a large reservoir of WNV infection that builds up in early spring (Nosal & Pellizzari, 2003). Second, bridging species, such as *Aedes albopictus*, feed on both humans and birds and are responsible for transmitting WNV to humans (Hunter cited in Nosal & Pellizzari, 2003). Notably, although mosquito transmission is the main vehicle for human disease, WNV also can be contracted through blood or organ donation, lactation, needle-stick injury, and exposure to laboratory specimens (Nosal & Pellizzari, 2003; Bren, 2003).

1.2 Vector Competence. Identifying the mosquito species that have the greatest potential for WNV transmission in Oregon is critical for prevention and control planning (Goddard, Roth, Reisen, & Scott, 2002). *Vector competence* is defined as the "intrinsic permissiveness of an arthropod for the infection, replication, and transmission of a virus" (Goddard et al, 2002). A mosquito is a competent vector for WNV if it possesses a suitable internal environment for efficient uptake, development, and output of the virus.

The first factor that may allow WNV to exploit a vector is *uptake*, or viral entry into a vector during a bloodmeal (Spielman & Rossignol, 1987). Uptake is eliminated as a component of vector competence, however, if the virus is inherited (vertically transmitted) by the mosquito (Spielman & Rossignol, 1987). Because WNV has been vertically transmitted in laboratory trials in the *Culex pipiens* species, evidence suggests that a mosquito may become infected without taking a bloodmeal (Dohm, Sardelis, & Turell, 2002). Vertical transmission is significant because it may allow WNV to survive within the mosquito during the winter months of vector inactivity, initiating a new epizootic cycle of WNV in the spring (Dohm & Turell, 2001). Although research has demonstrated vertical transmission of WNV in laboratory settings, the epidemiological significance of this is unknown.

The second factor that may allow WNV to exploit a vector is *development*, or the capacity to mature once the virus has entered the mosquito (Spielman & Rossignol, 1987). The virus must overcome several barriers during this phase before it can be transmitted to another host (Goddard, J., 2002). The virus must first bypass the gut wall of the mosquito. Next, the virus must survive and develop in the mosquito's tissues. Finally, the virus must penetrate the mosquito's salivary glands (Goddard, J., 2002). Once these obstacles have been surmounted and the extrinsic incubation period completed, the mosquito may be capable of transmitting the virus to susceptible hosts while taking its next bloodmeal.

The third factor that may allow WNV to exploit a vector is *output*, or the quantity of pathogen delivered to the host (Spielman & Rossignol, 1987). If an infected mosquito is ingested passively by a susceptible host, then output is eliminated (Spielman & Rossignol, 1987). Intensity of disease in humans is related to the viral output from the mosquito vector (Spielman & Rossignol, 1987).

1.3 Vectorial Capacity. In addition to vector competence, external factors are also significant components of efficient virus transmission. These external factors are termed *vectorial capacity*, a synthesis of "those variables that affect the ability of a vector to transmit disease, including vector competence" (Spielman & Rossignol, 1987). Vectorial capacity can be expressed mathematically (cited in Spielman & Rossignol, 1987):

$$VC = ma \frac{P}{F} e^{-n/E} E$$

Where *ma* = number of bites per human host per day

P = number of bloodmeals taken on human hosts

F = days between bloodmeals

n = extrinsic incubation period

E = vector's life expectancy

e = natural logarithm base, a constant of ~2.718

The capacity of an arthropod population—such as mosquitoes—to transmit a virus depends upon vector competence (contributing linearly), vector abundance (*m*) (contributing linearly), narrowness of the host range (P) (contributing as a square), frequency of feeding (F) (contributing as a square), and longevity (E) (contributing exponentially) (Spielman & Rossignol, 1987). Mosquito control efforts designed to decrease risk of virus transmission to humans must plan to reduce particular components of vectorial capacity (Spielman & Rossignol, 1987). Because longevity (E) contributes exponentially to the equation, it is usually the most essential component of vectorial capacity to be decreased. If longevity (E) is less than the extrinsic incubation period (*n*), transmission of a virus to a human host will not occur.

1.4 WNV—Determination of Risk. WNV has been recovered in 43 species of mosquitoes since 1999 (CDC-WNV, 2003). Discovering WNV in these mosquitoes, however, does not indicate that all 43 species efficiently transmit the virus. Vector competence and vectorial capacity should be evaluated to determine which species are capable of transmitting WNV in Multnomah County, as well as the risk these species pose for potential disease outbreak.

In California, Goddard et al. (2002) tested 10 species of mosquito for vector competence for WNV. All species of mosquito tested were competent laboratory vectors of WNV, although infection rates varied by species, dose, and incubation period. Six of the 10 mosquito species tested in California also are present in Multnomah County, including *Culex pipiens, Culex stigmatosoma, Culex tarsalis, Aedes (Ochlerotatus) sierrensis, Culista inornata* and *Aedes vexans* (McConnell, 2003).

Among the species tested in California, the *Culex* species were the most efficient vectors (Goddard et al., 2002). For this reason, *Culex pipiens, Culex stigmatosoma,* and *Culex tarsalis* may contribute significantly in the amplification and maintenance of WNV in the Western United States. As discussed previously, *Culex pipiens* also has been suggested as a host for overwintering of flaviviruses such as WNV (Goddard et al., 2002).

This study further indicated that *Culista inornata* demonstrated relatively high infection and moderate transmission rates, and may contribute minimally to the amplification and transmission of WNV (Goddard et al., 2002). Additionally, *Culista inornata* may potentially contribute to maintenance of WNV in the winter because this species is active during the winter months (Goddard et al., 2002). *Aedes vexans* demonstrated moderate infection and transmission rates for WNV. Mammalian feeding preferences decrease this species' potential as an enzootic vector, however (Goddard et al., 2002). Finally, *Aedes (Ochlerotatus) sierrensis* demonstrated low vector competence and mammalian feeding preferences. This species, therefore, likely would not be an enzootic or bridge vector for WNV in this region (Goddard et al., 2002).

In another study examining vector competence of mosquitoes from the New York area, *Aedes albopictus* was determined to be highly efficient laboratory vectors of WNV (Turell et al., 2001). *Aedes albopictus* is another mosquito species known to be present in Multnomah County (McConnell, 2003). This species may contribute significantly to the transmission cycle of WNV as it feeds on birds, mammals, and humans, making *Aedes albopictus* an ideal bridge vector (Turell et al., 2001). The presence and vector competence of the previously mentioned mosquito species indicates that disease transmission to humans is possible if WNV arrives in Oregon this spring.

Factors related to vectorial capacity also must be considered when evaluating the risk for disease outbreak posed by vector competent mosquito species. Such factors include abundance of mosquito species, feeding behaviors, life expectancy, and extrinsic incubation period. Additional factors to be considered related to vectorial capacity include narrowness of the host range, relative virulence of the virus, and presence of hosts susceptible to the disease (Dohm, O'Guinn, & Turell, 2002).

Finally, environmental factors should be considered in evaluating risk for WNV transmission. Reiter (2001) reports, "the ecology, development, behavior, and survival of mosquitoes and the transmission dynamics of the diseases they transmit are strongly influenced by climactic factors." Such factors include rainfall and temperature. For example, excessive flooding may increase the abundance of mosquito species that are known to transmit WNV to humans, such as *Aedes vexans* (P. Rossignol, personal communication, February, 2004), and increased environmental temperatures can enhance the vectorial capacity of mosquito species (Reiter, 2001).

In laboratory trials, Dohm, O'Guinn, and Turell (2002) found that *Culex pipiens* mosquitoes maintained at warmer incubation temperatures were more likely to become infected with WNV, and infections became disseminated more rapidly than in mosquitoes of the same species maintained at cooler temperatures. These findings suggest that warmer environmental temperatures may increase vectorial capacity by decreasing the extrinsic incubation period needed to efficiently transmit WNV (Dohm, O'Guinn, & Turell, 2002).

Although the results from this study were gleaned only from laboratory trials, above-average temperatures have been associated with WNV outbreaks in real-life settings, including New York City, Vogograd, Russia (Platonov et al. as cited in Dohm et al., 2002), and Bucharest, Romania (Hat et al., Savage et al. as cited in Dohm et al., 2002). It is difficult to determine, however, the extent to which environmental temperatures contributed to disease transmission in these WNV outbreaks.

As demonstrated, numerous, complex factors must be critically evaluated to estimate the risk of WNV transmission to humans. Barker, Reisen, and Kramer (2003) report, "clearly defined thresholds to forecast human risk and provide targets for intervention are poorly collated and inconsistent among regions and agencies. This special heterogeneity is expected due to differences in local ecology and productivity that make numerical targets elusive and spatially variable." In Multnomah County, the variables that contribute to WNV transmission must be delineated to forecast human risk and respond appropriately to the threat of disease transmission. Knowledge of mosquito biology, mosquito behavior, and local conditions should be used to select and implement the most appropriate interventions on a site-specific basis (Shapiro & Micucci, 2003).

1.5 WNV—Clinical Presentation. WNV infects over 150 susceptible species of birds and animals (Nosal & Pellizzari, 2003). As described previously, humans are among the species vulnerable to illness as a result of WNV infection. WNV has an incubation period of 3 to 14 days in humans, and data indicate that approximately 20% of infected individuals will develop febrile illness (Nosal & Pellizzari, 2003). Among those who develop illness, clinical manifestation can range from flu-like illness to death.

Solomon and Vaughn report that characteristics of illness may include fever with chills, malaise, headache, backache, arthralgia, myaligia, and retro-orbital pain (as cited in Solomon, Obi, Beasley, & Mallow, 2003). Other clinical features may include anorexia, nausea, vomiting, diarrhea, and sore throat (Solomon et al., 2003). Sampathathkumar (2003) reports that approximately 1 in 150 infected persons develops severe central nervous system complications, including meningoencephalitis or isolated cases of encephalitis or meningitis. Additionally, acute flaccid paralysis has been associated with WNV in severe cases of illness (Sampathathkumar, 2003).

1.6 Mosquito Control. As demonstrated, illness related to WNV infection can have serious consequences. Controlling vector mosquitoes responsible for the transmission of WNV, therefore, is critical to decreasing the risk of human illness. Reducing components of vectorial capacity is a critical means of preventing human illness. For example, decreasing mosquito longevity limits the transmission of WNV because infected mosquitoes would not survive long enough to become capable of transmitting the virus. Adult mosquito longevity typically is reduced by using insecticides in a residual formulation or as a space spray to attack adult mosquitoes (Spielman & Rossignol, 1987). This technique is called *adulticiding*.

Limiting risk of human illness, however, is not the only goal of mosquito control efforts. Controlling nuisance mosquitoes also is essential for enhanced community livability and human quality of life. Efforts to limit mosquito annoyance generally aim to reduce mosquito abundance, achieved through public education, habitat reduction, mosquito avoidance, mosquito larvae destruction (larvaciding), and adulticiding. Programs that utilize a combination of these components to control mosquito populations are frequently called *Integrated Pest Management* (IPM) programs.

1.7 Integrated Pest Management. According to the IPM institute, "IPM is an approach that maintains a high standard of pest control while reducing reliance on high-risk pesticides. IPM includes regular monitoring to detect problems early, acting against pests only when necessary, choosing the most effective option with the least risk to people and the environment, and applying knowledge about pest biology to create long-term, prevention-based solutions" (IPMI, 2002). Oregon utilizes an IPM program for mosquito management (both vector and nuisance) that includes surveillance, public education, habitat reduction, mosquito avoidance, larvaciding, and adulticiding.

1.7.1 Surveillance. Oregon's surveillance and response plan allows state and local agencies to prepare for and respond to the presence of mosquito-borne diseases, including WNV (DeBess, 2002). The Department of Human Services manages a statewide surveillance system for collection and management of WNV data, including: 1) mosquito surveillance which requires collection and identification of adult and larval mosquitoes to determine species composition, geographic distribution, and quantity of potential vectors of disease in each county (DeBess, 2002); 2) bird and mammal surveillance which requires community and professional reporting of dead birds to track presence of WNV illness (DeBess, 2002). Select birds will then be tested to confirm WNV illness (DeBess, 2002). Guptill, Julian, Campbell, Price, and Marfin (2003) indicate that in counties where bird illness and death are found early in WNV season (spring or summer), subsequent WNV disease in humans is more likely; and 3) human surveillance that requires monitoring and sampling of human disease outbreaks. Oregon utilizes a passive reporting system that depends on health care providers and laboratory personnel to monitor and report cases of human encephalitis (DeBess, 2002).

1.7.2 Public Education. The provision of public information is considered essential in Oregon. Enhanced public awareness and illness prevention education encourage participation in surveillance activities, habitat reduction, and mosquito avoidance (DeBess, 2002). Public information also increases health care providers' knowledge of arboviral illness and encourages prompt reporting of all cases of human illness (DeBess, 2002).

1.7.3 Habitat Reduction. Habitat reduction is achieved through modifying or eliminating breeding areas through reducing flooding and/or minimizing sources of standing water. Water management activities include maintaining or draining pools, plant saucers, birdbaths, and tires. In addition, water management practices require cleaning roof gutters, placing pumps in landscape ponds, and using mosquito fish in local ponds (DeBess, 2002).

1.7.4 Mosquito Avoidance. Reducing exposure to biting mosquitoes requires restricting outdoor activities during hours that mosquitoes are biting, wearing appropriate clothing, and using repellant as needed (DeBess, 2002). Fradin and Day (2002) tested the relative efficacy of various insect repellants, including: seven botanical insect repellents; four products containing DEET; a repellent containing IR3535; three repellent-impregnated wristbands; and a moisturizer. Duration of protection was measured using "arm-in-cage" methods, where participants inserted their repellant-treated arms into a cage housing unfed mosquitoes (Fradin & Day, 2002). Each of the 16 repellants was randomly tested three times on 15 participants in a controlled laboratory environment. The results of this study indicated that DEET-based products far exceeded the other repellants, providing complete protection for the longest duration (Fradin & Day, 2002).

When the above-mentioned techniques are not sufficient, chemical or biological agents—such as organophosphate and pyrethroid pesticides—may be utilized to control mosquitoes at immature stages (larvaciding) or adult stages (adulticiding) of life (DeBess, 2002).

1.7.5 Larvaciding. Larvaciding uses chemical or biological agents to kill mosquito larvae or pupae by aerial or ground applications (DeBess, 2002). The objectives of larvaciding are: 1) to control immature stages in the breeding habitat before adult populations can disperse; and 2) to decrease mosquito populations to levels that reduce the risk of disease transmission (DeBess, 2002). Larvaciding is generally considered more cost-effective and target-specific than adulticiding (DeBess, 2002), and can be applied in a solid form, which limits human exposure (Shapiro & Micucci, 2003). Additionally, some larvacide agents are mosquito-specific, and have relatively little impact on the environment and human health when used appropriately (Shapiro & Micucci, 2003). Larvaciding generally is considered the most effective method for pest control, whereas adulticiding is considered the most effective method for controlling the transmission of disease.

1.7.6 Adulticiding. In cases when disease transmission is currently taking place and/or other efforts have failed to reduce mosquito numbers, use of adulticides becomes the final option for mosquito control (DeBess, 2002; Nosal & Pellizzari, 2003). Heavy precipitation, flooding, high tides, environmental constraints, inaccessible larval habitats, missed breeding sites, budget shortfalls, absent employees, and/or equipment failures may necessitate the use of adulticides (Rose, 2001).

Adulticiding uses pesticides to kill adult mosquito populations using ultra-low-volume (ULV) spray dispersed by truck-mounted equipment or aircraft (DeBess, 2002). Mount, Biery, and Haile (1996) report the ULV method "involves the application of the minimum effective volume of an undiluted formulation of insecticide (as received from the manufacturer)." ULV has become the standard in mosquito control (over high-volume water or oil based sprays) for several reasons, including increased effective payload, more rapid and timely application, elimination of the formulation process, less handling of insecticide, and reduced application costs (Mount et al., 1996). Additionally, adult mosquitoes are easily controlled using insecticides at ultra-low rates. For example, malathion is often applied at 3 fluid ounces per acre for mosquito management, while rates as high as 16 fluid ounces per acre are often applied for agricultural practices (Rose, 2001).

Brattsen and Sutherland (2003) report that desirable environmental conditions for efficient ULV application include air temperatures that are 60°F or higher (60°F to 82°F are ideal), light intensity below 20 foot candles with light meter, wind velocity of 3 to 10 mph, and stable thermal conditions that allow the adulticide to travel at ground level. Adulticide applications should be performed after sunset or before sunrise, a time when the previously mentioned conditions are most likely to be present (Brattsten & Sutherland, 2003). Additionally, the ULV spray must drift through the mosquito habitat to provide adequate control of mosquito populations (DeBess, 2002). Adulticides currently labeled for use in the United States include the organophosphates naled and malathion, natural pyrethrins, and the synthetic pyrethroids permethrin, resmethrin, and sumithrin (DeBess, 2002). Adulticides must be applied according to the instructions on the label, which represent the law in the United States. Strict adherence to adulticide laws is critical, especially for independent and/or extension agencies, companies, or farmers that many not be monitored for compliance as regularly as centralized, government-based mosquito control agencies. Multnomah County anticipates using synthetic pyrethroids (see Appendix A, NPIC, 1998) in ULV formulation if necessary, although malathion (see Appendix B, NPIC, 2001) is also an option for control.

The use of adulticides as part of a mosquito control program, however, is complex and controversial. The efficacy of adulticiding in controlling mosquitoes has been debated. Furthermore, the public has become increasingly knowledgeable about pesticides and their potential adverse outcomes, resulting in increased community involvement in mosquito control issues (Ames, 2002). Due to the controversies related to adulticiding, the Multnomah County Health Department has assembled a diverse panel of professionals to discuss the use of adulticides as part of the county's IPM program. The panel will be meeting in April, 2004 to answer the following question: "under what circumstances should the Multnomah County Health Department use adulticides as part of the IPM program for mosquito control?"

This study consists of two major components: 1) a literature review designed to answer four specific research questions developed in conjunction with professionals at Multnomah County; and 2) phone interviews with individuals at varying vector control agencies in the United States to answer specific research questions developed in conjunction with professionals at Multnomah County. The information gleaned from the literature review and interviews will be compiled and provided to Multnomah County to assist the panel in answering the primary research question outlined above.

The four research questions to be addressed by the following literature review include:

1) What is a critical assessment of adulticide use for preventing mosquito-borne disease in the United States?
2) What are the demonstrable or reasonably anticipated human and ecological impacts of using adulticides as part of an IPM program for mosquito control in our community?
3) How is quality of life and community livability for humans impacted by mosquitoes?
4) What are the benefits and risks of adulticide use in addressing these quality of life and community livability issues?

Chapter 2-Literature Review

2.1 Efficacy of Adulticiding. Adulticiding is a component of Oregon's IPM program. Adulticide use has several limitations, however, that elicit controversy. Multnomah County is weighing the benefits and risks of adulticide use, therefore, in controlling transmission of WNV if it arrives in Oregon this spring.

Yap et al. (1997) report that both favorable and unfavorable results have been found with regard to the efficacy of ULV adulticide applications. This discrepancy may be attributed to differences in choice of adulticide, application rate, and degree of adulticide penetration into mosquito dwellings (Yap et al., 1997), as well as the ability (or inability) of adulticides to reduce certain components of vectorial capacity. Regardless of the cause, efficacy of ULV adulticides to disrupt or reduce transmission of WNV to humans remains uncertain. What is certain, however, is that "the true efficacy of such a widely used and costly control method deserves far greater attention than it has received in the past" (Reiter et al., 1990).

2.1.1 General studies. Many mosquito abatement districts rely on decreasing mosquito abundance—only one component of vectorial capacity—to interrupt encephalitis transmission. A study by Walton, Workman, Randall, Jiannino, and Offill (1998) evaluated the efficacy of mosquito control measures in California wetlands and found that "in order to reduce mosquito populations, larvaciding and effective adulticiding needed to be carried out concurrently." Although decreasing abundance may be an effective treatment to decrease mosquito nuisance, Olson, Reeves, Emmons, and Milby report that "encephalitis virus transmission appears to be capable of proceeding at low vector abundance levels" (as cited in Barker et al., 2003). The use of adulticides, therefore, may not sufficiently lower mosquito abundance to reduce transmission of WNV to humans (Shapiro & Micucci, 2003). Howard and Oliver (1997) evaluated the long-term outcome of repeated pesticide spraying on the abundance of mosquito vectors of EEE. The organophosphate pesticide naled was sprayed repeatedly over the course of 11 years in two New York swaps (Howard & Oliver, 1997). Although naled applications successfully achieved short-term reductions in mosquito abundance, long-term studies indicated that repetitive applications had no noticeable impact on the enzootic amplification of EEE (Howard & Oliver, 1997). The results were gleaned from one of the few long-term studies identified; however, it is difficult to ascertain the numerous factors that may have contributed to the outcome of this study over the 11-year period. Further long-term studies are needed to determine if repeated adulticide spraying has any impact on the enzootic amplification of arboviruses, including West Nile.

Furthermore, the efficacy of adulticiding may be impacted by the varying stages of bloodmeal digestion taking place during ULV applications. Reiter, Elison, Francy, Moore and Campos (1990) performed field research evaluating the impact of ULV resmethrin by monitoring daily oviposition rates of urban *Culex* mosquitoes. The researchers observed a "well-defined oscillation effect" in susceptibility to ULV adulticides with a period corresponding to the gonothrophic cycle of the mosquito (Reiter et al., 1990). Although this observed pattern may be attributed to behavioral characteristics common to this mosquito species, it also may be attributed to changes in susceptibility that occur during the gonothrophic cycle (Reiter et al., 1990). The researchers speculated that susceptibility to insecticides "decreases after blood feeding, and gradually returns as the female becomes more gravid" (Reiter et al., 1990).

This theory of decreased insecticide susceptibility related to gonothrophic cycle was later tested in laboratory trials by Eliason, Campos, Moore, and Reiter (1990). Wind tunnel exposures using malathion and synergized resmethrin on adult *Culex pipiens, Culista melanura,* and *Aedes aegypti* found that susceptibility to insecticide aerosols varied with time depending on stage of bloodmeal digestion

(Eliason et al, 1990). The researchers reported that "substantial numbers of females survive the brief presence of aerosols because of increased tolerance associated with having taken a recent bloodmeal" (Eliason et al., 1990). This study suggested that for improved mosquito control, a second application of ULV adulticides—perhaps 2 days later—may be needed to kill remaining females that have digested their bloodmeals and are again more susceptible to insecticides (Eliason et al., 1990). Doubling the insecticide dosage may be another useful method to increase the efficacy of control efforts, when permitted by the label (Eliason et al., 1990).

Finally, Espinoza-Gomez, Hernandez-Suarez, and Coll-Cardenas (2002) evaluated the efficacy of ULV adulticiding in reducing the breeding grounds of *Aedes Aegypti* compared to an educational campaign devised to provide information about chemical and biological mosquito control. A randomized community trial was performed among 187 houses grouped in four blocks in Colima City, Mexico: 1) 46 houses received ULV malathion spraying and temefos larvaciding; 2) 45 houses received no treatment of any kind; 3) 49 houses received *both* education and ULV malathion spraying/temefos larvaciding; and 4) 47 houses received the educational campaign alone (Espinoza-Gomez et al., 2002).

Results of this study indicated that the educational campaign alone reduced the breeding places of *Aedes aegypti* more effectively than malathion spraying, while a *combination of both treatments* (educational campaign plus adulticide use) demonstrated a *"discrete negative interaction"* (Espinoza-Gomez et al., 2002). The authors suggested that adulticide treatments performed *in conjunction with* an educational campaign may reduce the efficiency of the educational campaign, possibly due to a false sense of security created by spraying (Espinoza-Gomez et al., 2002).

Although these findings are based on larval control as opposed to adult mosquito control, significant information regarding the efficacy of adulticiding is provided. If adulticiding creates a false sense of protection against mosquitoes and disease transmission, people may be less likely to participate in source reduction activities, thereby increasing mosquito breeding grounds and abundance of mosquito larvae that will eventually develop into adult mosquitoes. Limitations of this study, however, include: 1) the extensive educational campaign, which included an average of three visits per household to provide education about mosquito control, may not be realistic or feasible for larger, more populous communities; and 2) the outcomes demonstrated by Espinoza-Gomez would vary according to the community under study depending on environment, targeted mosquito species, community interest and involvement, and community leader participation.

2.1.2 Mosquito resistance. The efficacy of adulticiding also is impacted by mosquito resistance, a phenomenon that occurs when an insect survives a dose of pesticide that would normally be fatal (Hemingway, Field, & Vontas, 2002). Hemingway and Ranson report that pesticide resistance is common among vector mosquitoes (cited in McCarroll et al., 2000). Different mosquito species may inherently vary in susceptibility to different adulticides (Rose, 2001), and multi-resistance to several classes of insecticides is common (Buss et al., 2002; McCaffery, & Callaghan, 2002).

Insecticide resistance is a troubling for several reasons. Buss et al. (2002) report, "aside from the obvious disease implications, resistance may result in reduced levels of control, the use of increased numbers of applications, and the adoption of increased application rates. These factors may lead to a higher environmental load, with the consequent concerns for health and environmental damage."

Toutant reports that insecticide resistance is frequently attributed to a loss of sensitivity of the mosquito's acetylcholinesterase enzyme to organophosphates (as cited in Weill et al., 2003). Thompson (2003) reports that other mechanisms—

such as sodium channel mutations and cytochrome P-405 enzymes—are associated with resistance to pyrethroids. Although numerous studies related to mosquito resistance have been performed, the results of these studies cannot be generalized to Multnomah County because resistance can vary widely from region to region. Mosquito resistance, however, is relatively easy to monitor with insecticide bioassays (Hemingway et al., 2002). Monitoring for resistance using phenotypic or molecular identification, therefore, is an essential part of any regional comprehensive mosquito control program to ensure appropriate, effective use of adulticides (Rose, 2001; Thompson, 2003).

2.1.3 Application techniques. Another concern related to the efficacy of adulticiding is sub-optimal application practices. Steinke and Yates (1987) report that some aspects of ULV adulticiding—such as gravity, atmospheric conditions, wind speed and direction, and interactions with plant canopy—are not within the control of the applicator and can affect control efforts adversely. For example, Reiter reports that spray trucks produce a fairly narrow swath of adulticide whose dispersion can be blocked by buildings and vegetation (as cited in Enserick, 2002). In residential areas, the quantity of homes, structures, and vegetation may block ULV adulticide aerosols, thereby decreasing the amount of insecticide available to contact flying mosquitoes.

A study performed by Lothrup, Lothrup, and Reisen (2002) evaluated the impact of nocturnal microhabitat distribution of adult *Culex tarsalis* on control effectiveness. This study revealed that adulticide evaluations were impeded by changes in wind speed and direction that resulted in a failure for the researchers to control adulticide drift and to target specific areas consistently (Lothrup et al., 2002). Another study performed by Tietze, Hester, and Shaffer (1994) evaluated the mass recovery of malathion in simulated open field tests. This study revealed that air instability accounted for a drastic change in the deposition patterns of

ULV-applied malathion. These studies demonstrate the challenges inherent to ULV application practices.

2.1.4 Mosquito behavior. The effective use of adulticides requires an awareness of which mosquito species are being targeted for control, as well as the behavior patterns intrinsic to these species. Adulticiding may be impacted negatively by a lack of knowledge of complex mosquito behaviors—such as resting habits—demonstrated by a targeted species. Reiter, Eliason, Francy, Moore, and Campos (1990) report that many mosquito species remain inactive during the period between taking a bloodmeal and laying their eggs. Reiter reports that because insecticides kill only flying mosquitoes, those that are resting in areas protected by structures or vegetation may escape the aerosol and survive adulticide applications (as cited in Enserick, 2002).

One previously mentioned study performed by Lothrup et al. (2002) evaluated the impact of nocturnal microhabitat distribution of *Culex tarsalis* on control efforts. This study demonstrated that female *Culex tarsalis* "congregated along elevated ecotones and were significantly less abundant flying over low vegetation or under and over elevated vegetation" (Lothrup et al., 2002). ULV particles, however, did not reach mosquitoes resting within or under the vegetative canopy or along lee-ward ecotones, because these mosquitoes were protected by the elevated vegetation (Lothrup et al., 2002). The researchers concluded that control efforts were negatively impacted by the inability of sprayed insecticides to penetrate the vegetative ecotones where *Culex tarsalis* frequently rest (Lothrop et al., 2002). These findings help to explain why repeated adulticide applications may fail to interrupt disease transmission (Lothrup et al., 2002). As stated previously, however, a limitation of this study was the changes in wind speed and direction that impeded adulticide evaluations.

Furthermore, adulticiding efforts may be impacted by mosquito behaviors related to feeding and host-seeking. For example, Reiter reports that *Culex pipiens* are canopy feeders—an essential fact to consider when applying ULV adulticides (as cited in Enserick, 2002). Treatment will be ineffective against this species if adulticides are not applied to reach canopy levels. Additionally, research by Reisen, Lothrup, and Meyer (1997) indicates that *Culex tarsalis* generally perform host-seeking activities—during which the mosquito would be active and exposed to ULV applications—in the early evening before the formation of the thermal conditions necessary for effective ground applications of adulticide. Adulticiding when *Culex tarsalis* is most active, therefore, would not be optimally effective (Reisen et al., 1997).

Time of host-seeking for female mosquitoes may be altered by many factors, including weather, mosquito control activities, distance of the host from resting sites, host avoidance behavior, and mosquito population demography (Reisen et al., 1997). Mosquito control efforts are further complicated, therefore, by the inability to precisely estimate the time of day when adult females will be most active.

Notably, *Culex pipiens* and *Culex tarsalis*—the species discussed previously—are only two species of mosquito that participate in the transmission of WNV. Reiter reports that each species of mosquito capable of WNV infection has its own peculiarities, thereby requiring different control methods (as cited in Enserick, 2002). Ultimately, Reiter believes that improved control practices will require a more intimate knowledge of mosquitoes—including behavior patterns related to resting and feeding (as cited in Enserick, 2002).

In conclusion, the efficacy of adulticiding can be influenced by many factors. It is essential to use appropriate methods, therefore, to continually monitor the efficacy of mosquito control programs. First, monitoring should be performed to ensure that adulticide applications result not only in decreased mosquito abundance, but more importantly in decreased transmission of WNV. Second, mosquito resistance should be monitored to ensure utilization of an appropriate adulticide to control targeted species. Finally, it is imperative to monitor that adulticide applicators are trained adequately, all equipment is working appropriately, environmental conditions are optimal for effective application, and adulticiding is being performed at appropriate times and locations. Performing monitoring programs, when feasible, will ensure that an adulticiding program is optimally effective, resources are not wasted, and the public is not unnecessarily exposed to pesticides.

2.2 Human Health Impacts of Adulticiding. The Environmental Protection Agency (EPA) finds that both pyrethroids and malathion can be used for public health mosquito programs "without posing unreasonable risk" to human health when applied according to the label (EPA, 2002). Pyrethroids pose slight risk of acute toxicity to humans, however, and can adversely affect the nervous system in high doses (EPA, 2002). Malathion. at high doses, can overstimulate the nervous system causing nausea, dizziness, or confusion (EPA, 2002). Severe high-dose poisoning with malathion can cause convulsions, respiratory paralysis, and death (EPA, 2002).

2.2.1 Deposition of ULV adulticides onto body surfaces. Serious illness and death can occur as a result of adulticide exposure. These occurrences are not common, however. In general, the amount of insecticide utilized for ULV applications is not sufficient to cause serious illness in a healthy adult. One study by Moore et al. (1993) compared the deposition of malathion from a truck-mounted ULV aerosol generator onto human body surfaces with published dermal LD50 values for mammalian toxicity. Deposition was monitored via sterile gauze placed on body surfaces of three human subjects to quantify dermal exposure to malathion from ULV spraying. The first two subjects were standing 7.6 m and 15.2 m downwind from the spray vehicle, respectively, while the third subject jogged in the same direction and immediately downwind of the spray vehicle (Moore et al., 1993).

The researchers determined that "calculated malathion dermal exposures were less than the acute lethal dose for a human subject by four orders-of-magnitude or more," and "at 1.5 m downwind from the spray source, an adult male weighing 70kg would require 36,799 separate applications to accumulate the reported LD50" (Moore et al., 1993). These findings suggest that the ultra-low doses of insecticide utilized in mosquito control practices—along with the application processes used—are unlikely to result in human mortality from dermal exposures to healthy adults. Limitations of this study, however, include: 1) the health effects of inhalation were not evaluated; 2) comparisons were not drawn for people smaller in stature, such as women and children, and 3) no references were made regarding the health effects of exposure to ULV adulticides for people with increased susceptibility to pesticide-related illnesses (e.g. people with allergies).

2.2.2 Health effects of ULV adulticiding. Human exposure to adulticides in residential areas is uncommon due to low rates of application, performing treatments at night while people are indoors, providing special training to pesticide applicators, and offering public education and pre-notification of spraying (Rose, 2001). When exposure to adulticides from routine ULV applications does occur, however, it is not uncommon for minor, temporary health effects to arise.

Numerous agencies have performed research to determine the safety of adulticiding as part of an IPM program. In New York, an Environmental Impact Statement prepared by the Department of Health and Mental Hygiene found that adulticides have the potential to cause skin, respiratory, and eye irritation; however, the overall risk to human health from adulticiding is less significant than health effects due to mosquito-borne infection (as cited in Lopez and Miller, 2002).

Additionally, a comprehensive literature review, risk assessment, and epidemiologic and attributable risk analysis of adulticide use was performed in

Westchester, New York (Shapiro & Micucci, 2003). The findings from these studies suggest that no significant health effects would be expected from adulticides used according to the directions on the label, aside from short-term skin or respiratory effects, and would not increase asthma or other respiratory effects significantly. Similar conclusions were reached by the EPA and the Pest Management Regulatory Agency (Shapiro & Micucci, 2003).

Wilkes (2000) reports that a common complaint following topical exposure to ULV adulticides is short-term skin parenthesias—sensations of burning, tingling, numbness, or itching. Because pyrethroid penetration of dermal surfaces is poor and its metabolism is rapid, such doses are far too small to cause systemic toxicity (Wilkes, 2000). Skin paresthesias, therefore, are considered a nuisance side effect of pyrethroid exposure rather than a symptom of toxicity (Wilkes, 2000).

Another possible health effect of pyrethroid exposure is short-term immunosupression. Hadnagy, Leng, Sugiri, Ranft, and Idel (2003) performed a mutilparametric analysis of immune components before and after exposure to low levels of pyrethroids used during a professional indoor pest control operation. A relatively small sample size of 61 people participated in the study, and their immune components were tested at 1 day, 3 days, 4-6 months, and 10-12 months after exposure. The researchers found that indoor pyrethroid exposure following a pest control operation produced immunosupression for the first one to three days following exposure (Hadnagy et al., 2003). This immunosupression was subtle and reversible, however, and may have underlain compensatory mechanisms of normal immuno-regulation (Hadnagy et al., 2003). Hadnagy et al. report that further research is indicated in this area, especially with respect to children, the elderly, and those with allergies. Additional research also is needed to determine if similar immune response arises from exposure to *outdoor* ULV adulticide application with pyrethroids.

As described previously, the most common health effects resulting from ULV adulticide exposure are minor and reversible. More serious health outcomes have occurred, however, from exposure to these insecticides. A surveillance study performed by the CDC (2003) identified 133 patients ill from exposure to insecticides utilized in mosquito control efforts in nine states between April 1999 and September 2002. Of these 133 patients, 2 were definite cases of insecticide-related illness, 25 were probable cases, and 106 were possible cases (CDC-surveillance, 2003). Ninety-five of the cases were associated with organophosphate pesticides (malathion, 64 cases), while 37 cases were associated with pyrethroids (sumithrin, 24 cases; resmethrin, 10 cases). One case of illness was considered high severity in which a 54-year-old woman died from exacerbation of asthma and chronic obstructive pulmonary disease as a result of sumithrin exposure. Sumethin—a synthetic pyrethroid—passed through her operating window fans and window air conditioner causing a fatal exposure.

The remaining cases of illness were either mild (65.4%) or moderate (33.8%) in severity (CDC-surveillance, 2003). The CDC reported that 66.2% of cases were associated with respiratory effects and 60.9% of cases were associated with neurological dysfunction. Additional effects noted were gastrointestinal (45.1% of cases), ocular (36.1% of cases), dermal (27.1% of cases), cardiovascular (12.0% of cases), renal-genitourinary (3.0% of cases), and miscellaneous (28.6% of cases). Findings from the CDC, Reigert & Roberts, and Wagner all suggested that these health effects may be due to irritant or allergic responses either to an insecticide *or* to its carrier (as cited in CDC-surveillance, 2003). Additionally, the CDC noted that anxiety related to insecticide use for mosquito control may be responsible for symptoms in some persons.

2.2.3 Health concerns for special populations. Considering the health of individuals or groups that are frequently exposed or are particularly sensitive to adulticides is vital. For example, health concerns may arise for mosquito abatement employees who routinely handle cholinesterase-inhibiting chemicals—such as organophosphate pesticides. Exposure to cholinesterase-inhibiting chemicals can overstimulate the nervous system, resulting in nausea, dizziness, confusion, and respiratory paralysis and death in very high doses (Shapiro & Micucci, 2003).

One small study performed in California by Ames, Narveson, Mengle, and Womeldorf (1988) examined cholinesterase depression as a result of exposure to cholinesterase-inhibiting chemicals among 65 mosquito abatements employees. This study found that 1.5% (1 in 65) of pesticide applicators working in mosquito abatement districts presented with cholinesterase depression below the worker's baseline at levels that exceed the *current* Worker Health and Safety regulations for agricultural applicators in California. Due to the small sample size, the results of this study cannot be generalized to other mosquito abatement districts. This study effectively demonstrates, however, the importance of ensuring that all employees performing ULV adulticiding adhere to safety precautions while handling and applying insecticides and are monitored for cholinesterase depression when feasible.

Another special population to consider is children, who are particularly susceptible to pesticide exposure for several reasons. Eskenazi, Bradman, and Castorina (1999) report that because of their tendency to perform hand-to-mouth activities, along with their proximity to potentially contaminated surfaces, children may be more highly exposed to pesticides than adults. Additionally, the National Research Council (NRC) reports that the intake of high amounts of food, water, and air per unit of body weight also may increase pesticide exposure for children (as cited in Eskenazi et al., 1999). Finally, the NRC reports that developmental immaturity may place children at higher risk for developing the adverse health effects associated with pesticide exposure (as cited in Eskenazi et al., 1999).

Numerous studies assessing the effects of pesticide exposure on children's health have been performed; however, very few (if any) have effectively evaluated the effects of chronic, low-dose exposures. Toxicological evidence in developing animals suggests that repeated exposure to low-level organophosphate pesticides may affect neurodevelopment and growth (Eskenazi et al., 1999). Additionally, it is plausible that organophosphate exposure may result in dysregulation of the autonomic control of airways in young children, thus contributing to the occurrence of asthma (Eskenazi et al., 1999). Further research is needed, however, to more accurately assess the impact of chronic, low-dose exposures of insecticides on children. Additionally, further research is needed to evaluate the health effects of low-dose pesticide exposure on other vulnerable sub-populations, such as pregnant and nursing mothers, the elderly, people with allergies, and people with immune-compromised health status.

Notably, many people are exposed to pesticides daily, whether from personal, municipal, agricultural, or mosquito abatement sources. Research performed to date, however, has assessed the *acute* health effects of pesticide exposure. Ames (2002) advocates that further research is needed to gain "an understanding of the effects of multiple chemical exposures, the interactions among pesticides, and the effects of chronic, low-dose exposures to develop an understanding of reproductive, developmental, and other non-acute effects of pesticide exposure." It is possible that ULV adulticiding—although not acutely toxic—may contribute to chronic health problems such as multiple chemical sensitivities, allergies, and cancer.

2.2.4 Limiting the health impacts of adulticiding. The CDC recommends that public health authorities perform the following actions to reduce the risk for negative health effects resulting from ULV adulticide applications. First, provide public notification of adulticide spraying times and locations, as well as appropriate advice about preventing exposures (CDC-surveillance, 2003).

Second, ensure that adulticide handlers and applicators meet state-mandated training and experience requirements to reduce insecticide exposure to themselves and others (CDC-surveillance, 2003). Third, implement IPM control strategies that emphasize larval control, habitat reduction, and judicious use of insecticides to control adult mosquito populations (CDC-surveillance, 2003). Following these recommendations may help to reduce the public's exposure to adulticides, as well as ease the public's fear and apprehension about ULV adulticiding in their community.

2.3 Ecological Impacts of Adulticiding. Adulticides approved for use in the United States are assumed to have *minimal* impacts on the environment and wildlife due to low environmental persistence, low rates of deposition, and low mammalian toxicity. ULV adulticiding *may* elicit adverse ecological impacts, however, that should be considered prior to any application.

2.3.1 Environmental persistence. Knepper, Walker, Wagner, Kamrin and Zabik (1996) evaluated the persistence of malathion and permethrin on sod grass following a single, ULV application in a suburban neighborhood. Grass samples were taken from sod blocks before adulticide application and at 15 minutes, 12 hours, 24 hours, and 36 hours after application. Mass of detected malathion ranged from 0 (undetectable) to 16.6mg/0.18m^2, and mass of detected permethrin ranged from 0 to 25.9mg/0.18m^2 (Knepper et al., 1996). Most detections of malathion and permethrin were from samples taken nearest to the road (7.6 meters away) at 15 minutes post-application (Knepper et al., 1996).

Regression analysis revealed that adulticide residues declined as a logarithmic function of time after spraying, indicating the adulticides evaluated in this study did not persist for long periods of time on grass surfaces following ULV application (Knepper et al., 1996). These results, however, cannot be generalized to different formulations of the adulticides under investigation, other adulticides not specifically evaluated, or persistence values for aquatic environments.

Additionally, the persistence of *repeated* ULV applications was not evaluated in this study.

2.3.2 Deposition rates. The low deposition rates of adulticides onto environmental surfaces decreases risk to non-target organisms. Tietze et al. (1994, 1996) evaluated deposition rates following truck-mounted ULV applications of malathion for both open field and residential environments, and found general trends suggesting that adulticide deposition decreased with distance from the spray head. In open field assessments, the deposition of ULV malathion 5 meters from the spray head was 33.4 ng/cm^2, which is 5.8% of the estimated theoretical mass of 577 ng/cm^2 (assuming 100% deposition and homogenous distribution) utilized in laboratory acute-toxicity tests for non-target organisms (Tietze et al., 1994).

In residential areas, the deposition of malathion 11 meters from the street was 88.8 ng/cm^2, a value greater than that demonstrated in open field tests; however, still significantly lower than the theoretical mass of 577 ng/cm^2 (Tietze et al., 1996). The greater deposition rates found in residential areas may be attributed to equipment differences among studies, the effects of vegetation and structures that impede continuous drift, and/or problems inherent to ULV applications within a busy neighborhood where traffic slows the adulticiding truck (Tietze et al., 1996).

Jensen, Lawler, and Dritz (1999) evaluated deposition of pyrethrin, permethrin, and malathion in aquatic environments following truck-mounted ULV applications. Pre- and post-treatment surface water samples were collected from treatment and control wetlands for insecticide analysis (Jensen et al., 1999). Samples were collected within 2 hours before and within 1 hour after ULV adulticiding (Jensen et al., 1999). The analyses revealed that neither permethrin nor pyrethrin was detected in pre- and post-treatment water samples from treatment or control wetlands at a detection limit of .02 ppm (Jensen et al., 1999). Malathion was detected in post-treatment water samples from the treated wetlands at a detection limit of .006 ppm (Jensen et al., 1999). The detected malathion concentration, however, "was at an order of magnitude below the median lethal concentration dosage producing acute toxicity in fish" (Jensen et al., 1999). According to these findings, the researchers concluded that little insecticide was deposited in the water (Jensen et al., 1999).

These findings indicate minimal deposition (and perhaps minimal persistence) of malathion, permethrin, and pyrethrin in aquatic environments when applied according to label. As mentioned previously, however, adulticide deposition can vary greatly depending on environmental factors, such as air instability and wind speed and direction. Deposition rates and patterns, therefore, should never be assumed to be insignificant to terrestrial or aquatic environments and wildlife.

2.3.3 Toxicity. The EPA performs ecological risk assessments in the United States to determine toxicity of insecticides to non-target organisms. The EPA has found that both pyrethroids and malathion used in mosquito control programs do not pose "unreasonable risk to wildlife and the environment" (EPA, 2002). The EPA reports that pyrethroids are low in toxicity to mammals and are non-toxic to birds, but can be toxic to fish and bees (2002). Malathion is low in toxicity to mammals and birds, but highly toxic to insects, including honeybees (EPA, 2002). For these reasons, adulticides must be applied according to the directions on the label to ensure safety to susceptible species (EPA, 2002).

In an ecological risk assessment, the acute toxicity values are often obtained by "exposing the test organism to a constant concentration of the active ingredient over a 96-hour period, which is unlikely to happen in the natural environment due to degradation, dilution, partitioning to sediment or soil, and other dissipation pathways" (GEIS, 2001). Risk assessments, therefore, often are very conservative measures of toxicity to organisms. Empirical field data that provide results from realistic exposure scenarios is necessary to determine toxicity resulting from ULV adulticide applications.

2.3.3a Honeybees. Smith and Stratton (1986) report that while laboratory studies indicate that pyrethroids are toxic to bees, such adverse effects have not been demonstrated in field studies. The authors attribute this discrepancy to varying characteristics related to pyrethroids, including: 1) high repellant activity that encourages bees to evacuate a treatment area; 2) low dose rates; 3) low residual toxicity (Shires, 1985; Smart & Stevenson as cited in Smith & Stratton, 1986); and 4) relatively nonhazardous residual deposits on wildflowers (Murray, 1985; Smith & Stratton, 1986).

Field research has indicated that ULV malathion, however, can be toxic to bees—especially those that are not protected from the aerosol drift. Hester, Shaffer, Tietze, Zhong, & Griggs (2001) conducted a study to determine the effects of ground-applied ULV malathion on honeybees. Beehives were placed in open, forested, and control areas. Four beehives were placed in each treatment site at distances of 7.6, 15.2, 45.7, and 91.4 m from the street. Untreated control sites were placed upwind at a distance 1.2 km from the spray sites. Malathion adulticiding was performed four times over a period of 7 weeks between 8:00 p.m. and 8:30 p.m.

Results of the study indicated significant bee mortality in the open treatment area at both 7.6 m and 15.2 m from the street following the first and fourth sprays. Significant bee mortality also was noted in the forested treatment area at 7.6 m from the street following the fourth spray (Hester et al., 2001). Significant bee mortality was not noted in the control area. The researchers noted, however, that deposition rates of malathion were higher than expected due to low wind speed and a possible spray corridor in the open treatment area formed by pine trees. Higher deposition rates may have resulted in higher bee mortality. The researchers also noted that the highest bee mortality demonstrated in this study

(16.8 bees per hive) was within the acceptable range of natural bee mortality (Hester et al., 2001). Hester et al. report, however, that precautions still should be taken to protect bee hives from the possible detrimental effects of adulticiding.

The following recommendations, therefore, may help reduce honeybee mortality associated with ULV adulticiding: 1) reduce the deposition of the adulticides on the ground by reducing droplet diameter size to less than 30 μm (Zhong as cited in GEIS, 2001); 2) face the hives away from the direction of the wind (Zhong as cited in GEIS, 2001); 3) preserve the height of vegetation around a beehive to impede adulticide drift towards the hive and its bees (Zhong as cited in GEIS, 2001); 4) reduce the number of bees outside the hive by adding more supers (removable upper stories of a beehive) to cool the hive (Zhong as cited in GEIS, 2001); 5) avoid performing adulticiding during the daytime when bees are foraging and therefore exposed to aerosols (Caron as cited in GEIS, 2001); and 6) ensure that hives are more than 15.2 m away from roadways used for truck-mounted ULV adulticide applications (Hester et al., 2001).

2.3.3b Aquatic organisms. Malathion and pyrethroids also may be toxic to fish and aquatic invertebrates. Jensen, Lawler, and Dritz (1999) report that reliable field studies are vital to determining the effects of adulticide use on aquatic organisms. Although laboratory studies have proven valuable in determining and comparing toxicity of insecticides (Smith & Stratton, 1986; Tietze et al., 1995), they often conduct tests in simple, indoor environments using clean water and concentrations of insecticide that far exceed field exposures (Jensen et al., 1999).

Furthermore, Coats et al. report that insecticides may increase in toxicity if the environment is stressful to the organisms (as cited in Jensen et al., 1999), and behavioral differences between organisms in a laboratory setting versus a field setting can alter exposure to insecticides (Jensen et al., 1999). Finally, many studies evaluating the effects of insecticides on aquatic organisms apply adulticides directly to water resulting in significantly higher deposition than what would be observed following ULV applications (Jensen et al., 1999). For these reasons, the studies on aquatic organisms cited in this paper have been conducted in field settings using ULV applications.

Jensen et al. (1999) assessed whether ULV applications of permethrin, pyrethrin, and malathion reduced macroinvertrbrate abundance and biomass or killed mosquitofish in seven seasonal wetlands of California. ULV applications were identical to mosquito control practices in the area. Results indicated that all caged adult mosquitoes died within 24 hours, demonstrating good control of the targeted species (Jensen et al., 1999). All mosquitofish survived and appeared to be healthy in the 7 days following exposure to adulticides (Jensen at al., 1999). No decreases in the biomass or abundance of aquatic invertebrates were noted. Total numbers of aquatic insects demonstrated similar fluctuation in control wetlands versus treated wetlands (Jensen et al., 1999). These findings indicate that ULV adulticides, when applied according to label, may result in effective adult mosquito control without reducing the abundance of macroinvertebrates available for foraging wildlife or killing fish (Jensen et al., 1999).

An additional study performed by the Florida Department of Environmental Protection (FDEP) (1998) evaluated the potential affects of ULV adulticiding on macroinvertebrate in shallow, shoreline waters where a 100-foot buffer zone was observed during aerosol application. The FDEP performed a biological assessment of five lakes in response to repeated ground and aerial application of malathion to control the Mediterranean fruitfly. The malathion bait spraying was performed at 5-10 day intervals from May 3 through June 13, 1998, with macroinvertebrate communities being sampled from April 30 through August 4, 1998 (FDEP, 1998).

This study noted alterations in the macroinvertebrate community in all five lakes sampled. The most profoundly affected organism groups were those closely associated with bottom sediments, such as the turbellarians (flatworms) and oligochaetes (FDEP, 1998). Among these groups, dramatic reductions in abundance were noted. In some cases, the declining numbers of flatworms and oligochaetes were accompanied by dramatic increases in water mite abundance (FDEP, 1998). The increase in water mites may be attributed to the absence of flatworms, a possible predator of the mites (FDEP, 1998).

The researchers of this study ultimately recommended that "the 100 foot buffer zone around named water bodies should be maintained, or preferably increased. Any decrease in the width of this buffer zone could increase the severity of the ecological effects noted in this study" (FDEP, 1998). Notably, sampling of a control lake outside of the spray zone before, during, or after malathion treatment was not performed. The effects of natural temporal variability on the study results, therefore, were not assessed (FDEP, 1998).

2.3.3c Insectivorous birds. Because malathion and pyrethroids are broad spectrum insecticides, they are likely to kill insects other than mosquitoes. Secondary effects may occur when insectivorous birds do not have sufficient food to survive following ULV adulticide applications. Howe, Knight, McEwan, and George (1996) assessed the primary and secondary effects of ULV malathion spraying on the nestling growth and survival of Brewer's sparrows and Sage Thrashers in shrub-steppe habitat of southern Idaho in 1989 and 1990. The experiment consisted of reducing the insect food base using ULV malathion (applied at two or more times the application rate for mosquito control) while monitoring nestling growth variables and daily nest survivorship (Howe at al., 1996).

Results of this study indicated a statistically significant reduction in food (insects) on the treatment plots following ULV malathion spraying; however, no direct mortality of Brewer's sparrows or Sage Thrashers was detected either year of this study (Howe at al., 1996). Additionally, nestling growth and survival of

Brewer's sparrows and Sage Thrashers were not "severely affected" (Howe et al., 1996). Few differences were detected in nestling growth variables and survival rates between treatment and control plots, and these differences were not consistent across the two-year study period (Howe et al., 1996). Results from this study may not be generalizable to other species of bird in varying ecosystems, however, as the shrubsteppe area studied here was a relatively simple ecological system (Howe et al., 1996).

Another study by Pasqual (1994) evaluated the *short-term effects* of ULV malathion on breeding blue tits in Spain. One application of ULV malathion was performed on May 24 at a treatment plot 11 km away from a control plot. Arthropod density was measured "as the number of arthropods per 50 g of dry-weight foliage" (Pasqual, 1994). Blue tit nests were checked every 1 to 7 days from mid-April to early July to obtain detailed information about the nests and the baby birds. Pasqual found that the total arthropod abundance available as a food source in the treated area was similar to the untreated area with exception of the target pest, the green moth larvae (as cited in GEIS, 2001). In addition to these findings, the percentage of successful nests was similar in treated areas versus control areas, and no differences were identified in nestling weight (Pasqual cited in GEIS, 2001). Pasqual suggested that in evaluating the effects of food depletion on insectivorous birds due to ULV adulticiding, "it is more significant to assess the abundance of arthropods remaining alive after the treatment than the degree of arthropod mortality" (Pasqual, 1994). The long-term effects of adulticiding remains unknown (Pasqual, 1994), however, and the effects of repeated malathion applications were not evaluated in this study.

Notably, a reduction in arthropod abundance that is statistically significant may not be biologically significant, as demonstrated in the previous studies (GEIS, 2001). Post-spray arthropod abundance was sufficient enough that birds did not have to compete for food, and the birds were able to adapt by feeding on insects less susceptible to adulticide treatments (GEIS, 2001). Ultimately, the extent to which insectivorous birds are affected by adulticide treatments depends on "spatial coverage, duration and frequency of adulticiding and subsequent loss of insect prey" (GEIS, 2001).

A limitation of all field studies—including the previously mentioned studies—is that the conditions are site-specific to the time and place of that particular study (GEIS, 2001). Research outcomes related to the ecological impacts of adulticiding can be affected by numerous factors, including ecological variances among regions, environmental factors at the time of the study, and ULV application techniques. For these reasons, the results of empirical studies should be interpreted carefully (GEIS, 2001).

2.3.4 Additional concerns. As demonstrated previously, hazards to non-target organisms from ULV adulticiding alone tend to be limited due to the low rates of application, deposition characteristics, and appropriate application techniques. Protecting endangered species from *general* pesticide use, however, is becoming increasingly complicated. For example, difficulty assessing the chronic effects of low-dose exposures to pesticides is an ongoing issue. Peter deFur, an environmental toxicologist with Virginia Commonwealth University's Center for Environmental Studies, reports that "new research shows that certain pesticides become harmful at ultra-low doses, far below the levels where toxicologists normally stop testing…yet short-term tests for deadly effects remain the standard for pesticide registration" (as cited in Sachs, 2003/2004).

Scientists have discovered animals that suffer from abnormal development, deformities, decreased fertility, impaired senses, and/or increased susceptibility to predation and disease when exposed *to trace amounts* of certain pesticides (Sachs, 2003/2004). For example, Gary Feller and colleagues from the United States Geological Survey (USGS) have linked reduced tadpole survival and frog deformities to organophosphate pesticides, including malathion (as cited in

Sachs, 2003/2004). In a follow up study, USGS researcher Deborah Cowman found these insecticides to cause genetic damage in amphibians that likely result in the increased incidence of death and deformities (as cited in Sachs, 2003/2004). Frogs and other amphibians are especially vulnerable to pesticides in their waters; however, a similar vulnerability is seen in 26 threatened and endangered species of Pacific Salmon in the Northwest, including migrating coho, chinook, chum, sockeye, and steelhead (cited in Sachs, 2003/2004).

Another weakness in determining the ecological (as well as human) impacts of adulticiding, according to Sachs (2003/2004), stems from uncertainties posed by the "inert ingredients" on pesticide labels (see Appendix C, NPIC, 2000). Because the EPA only requires "active" ingredients to be tested, the emulsifiers, binders, spreading agents, and other chemicals are released into the environment without undergoing any safety assessment (Sachs, 2003/2004). Synergists—chemical additives that boost an active ingredient's toxicity—are of special concern to safety (Sachs 2003/2004).

A final challenge related to ecological impacts—mentioned previously related to human impacts—is understanding the risks related to cumulative and aggregate exposure to insecticides. Adulticides have a transient effect in that mosquito numbers return to pretreatment levels within a few days without reapplication of pesticides (Shapiro & Micucci, 2003). Multiple applications, therefore, are often required for effective mosquito control. Developing an understanding of multiple and repeated exposure to insecticides will help determine the accurate human health and ecological impacts of adulticiding for mosquito control.

2.4 Impact of mosquitoes on community livability. As previously mentioned, adulticiding is not only performed to control mosquitoes that vector disease, but also to control mosquitoes that pose nuisance concerns. Any mosquito species that bites humans—regardless of the mosquito's capability to transmit disease—can act as a nuisance mosquito. The presence of adult mosquitoes can trigger feelings of anxiety related to the threat of disease transmission, as well as annoyance related to the discomfort of repeated bites. This annoyance can interfere with quality of life, as it often forces people to avoid or limit outdoor activities such as sporting events, social events, barbeques, gardening, exercising, and other activities. It is difficult to determine the appropriate threshold for initiating adulticides to control nuisance mosquitoes; however, several studies have helped determine this threshold by quantifying the number of nuisance mosquitoes that may adversely affect community livability.

2.4.1 Studies on mosquito nuisance. John, Stole, and Olson (1987) performed surveys of urban, suburban, and rural residents in Jefferson County, Texas, to determine the public's perception of mosquito problems. Nine hundred sixty-seven usable surveys were returned and analyzed, representing a 39.0% response rate from property owners and a 13.7% response rate from renters (John et al., 1987). Results of this survey found that the average number of reported bites/hour/night was 9.2 in urban areas, 12.1 in suburban areas, and 14.9 in rural areas. Respondents who reported a mean of 5.7 mosquito bites/hour/night felt there was no mosquito problem around their home. Those who reported a mean of 7.7 bites/hour/night felt there was a mild problem, while those that reported a mean of 11.5 bites/hours/night indicated a severe mosquito problem (John et al., 1987).

Furthermore, the study indicated that mosquito problems occurred earlier in the year for urban residents. Families with children were more likely to report mosquitoes as a serious problem than families without children, men reported more bites than women, and age did not display any consistent relationship with the number of reported mosquito bites (John et al., 1987). In general, respondents of this survey were sensitive to the impact of insecticides on the environment and were supportive of implementing non-chemical control options (John et al., 1987).

Another survey conducted by Morris and Clanton (1988) in two Florida counties quantitatively determined what the public considers to be a nuisance mosquito problem. Nine hundred fifty-seven people responded to the mailed survey. On average, 1 bite every 30 minutes was considered a "slight" mosquito problem; 1 bite every 12 minutes was considered a "moderate" mosquito problem; and 1 bite every minute was considered a "bad" mosquito problem (Morris & Clanton, 1988). The researchers concluded, "our results tend to support the 56-year-old opinion of Headlee (1932) that 'when a human collector can take an average of more than one mosquito in 15 minutes, the density is sufficient to give the household trouble'" (Morris & Clanton, 1988).

Another study conducted by Robinson and Atkins assessed the attitudes and knowledge of urban homeowners in Virginia Beach towards mosquitoes (as cited in Read, Rooker and Gathman, 1994). This study evaluated cumulative (per night) exposure to mosquitoes and found that the mean number of bites reported tolerable by participants in one night was 8 (Read et al., 1994). Among those surveyed, 94% considered 10 bites a night a problem; 32% considered 4 bites a night a problem; and 13% considered 1 bite a night a problem (Read et al., 1994).

Finally, a study performed by Read et al. (1994) in the Minneapolis-St. Paul metropolitan area evaluated "whether residents' perceived annoyance levels and anticipated responses (reduced outdoor time, repellant use) were related to mosquito counts taken with a standard method at the same time and location." The study compared responses from individuals about mosquito annoyance (both *during* and *following* a five-minute period in their yard) with mosquito trap counts at the same time and location (Read et al., 1994).

Comparing trap counts to survey results, this study indicated that at trap counts of 2 or fewer mosquitoes in 5 minutes, annoyance was described as "moderate," with individual responses varying from "none" to "bad." Annoyance at trap counts between 3 to 30 mosquitoes in 5 minutes was described as "moderate" or "bad," with individual responses ranging from "slight" to "severe." Annoyance at trap counts of 40 or more mosquitoes in 5 minutes was described as "bad" or "severe" (Read et al., 1994).

Anticipated time outdoors and repellant use also were evaluated using trap counts (Read et al., 1994). Time outdoors decreased rapidly between mosquito trap counts of 2 and 8. For trap counts greater than or equal to 9, most people anticipated remaining outdoors for 30 minutes or less (Read et al., 1994). Additionally, anticipated use of insect repellant was reported as "possibly" for trap counts of 2 mosquitoes or less; "probably" for trap counts between 5 and 20 mosquitoes, and "definitely" for trap counts above 20 mosquitoes (Read et al., 1994).

In addition to these findings, bite counts were used to assess mosquito annoyance, anticipated time spent outdoors, and repellant use. Zero to 1 bites in 5 minutes elicited an annoyance response of "slight;" 3 bites in 5 minutes elicited an annoyance response of "moderate;" and 20 bites or more in 5 minutes elicited an annoyance response of "bad" (Read et al., 1994). Anticipated time outside was approximately 80 minutes at reports of 2 bites or less, 30 minutes at 6 bites, and 15 minutes at 15 bites (Read et al, 1994). Anticipated repellant use was reported as "probably not" at 0 bites, "possibly" at 2 bites, and "probably" at 7 bites per 5 minutes (Read et al., 1994).

Utilizing the findings of this study, the researchers concluded that "ideal control would keep mosquito levels low enough that most people would consider them 'none' or 'slight.' Keeping mosquito levels low enough that most people consider them no worse than 'moderate' would probably be acceptable, especially for those who use repellant. The minimum control expected would be to keep mosquito levels no more than what most people consider 'bad'" (Read et al., 1994).

Common limitations exist among the previously-mentioned mosquito nuisance studies. All four studies reviewed in this section relied on surveys to determine their results, which may result in bias related to differences among people who respond to a survey compared to those who do not. Additionally, the results of these studies would vary depending on regional factors, such as mosquito species, environmental conditions, and community culture. The general trends, however, may be applicable and useful in determining pre-defined thresholds for initiating, continuing, and/or terminating adulticide use for nuisance mosquitoes in Multnomah County.

2.4.2 Surveys on public perception of WNV and pesticides.

Community livability and quality of life can be greatly affected by an individual's perception of risk. Serosurveys performed in the United States indicate that many people feel threatened by WNV transmission as well as pesticide-related illnesses. These fears can affect a person's willingness or ability to enjoy outdoor activities.

The Harvard School of Public Health (HSPH) (January, 2003) surveyed 1001Americans nationwide—516 of whom live in high-mosquito areas. Among those respondents living in high-mosquito areas, 33% believe that someone in their family is either "very" (9%) or "somewhat" (24%) likely to get sick from WNV in the next 12 months (2003), while 32% of dog owners are concerned their pet might get WNV (HSPH, January 2003). In areas where there has been adulticiding in response to WNV, 91% of people in high mosquito areas approved the spraying, and 77% of Americans nationwide favored adulticiding if used to prevent the spread of WNV in their area (HSPS, January 2003).

Another survey by McCarthy et al. (2001) conducted in 2000 in an area of intense epizootic activity in southwestern Connecticut found that 58% of 730 respondents were "a little or very worried about getting WNV." Forty-eight percent of respondents were "a little or very worried about getting sick from the pesticides that were used to kill the mosquitoes" (McCarthy et al., 2001). When given a choice, however, people were more worried about WNV (37%) than pesticide-related illness (19%) (McCarthy et al., 2001).

Despite these findings, personal protection efforts have not been consistently utilized to protect against biting mosquitoes. The survey performed in Connecticut in 2000 revealed of the 730 respondents, 79% practiced at least one personal precaution. Fifty-five percent of respondents in this survey reported avoiding areas with mosquitoes, 44% used mosquito repellant, 43% wore protective clothing, and 29% avoided the outdoors at least sometimes (McCarthy et al., 2001). Only 7% of respondents reported practicing all four personal protection efforts (McCarthy et al., 2001). This survey also revealed 86% of respondents performed at least one source reduction activity. Fifty-five percent of respondents cleaned their gutters, 55% removed standing water, and 63% checked their screens. Only 25% of respondents performed all three mosquito source reduction activities, however (McCarthy et al., 2001).

A more recent study conducted by the Harvard School of Public Health (2003) revealed slightly less optimistic results. A national survey of 1015 Americans, with 471 respondents living in high-mosquito areas, was conducted. Among those living in high-mosquito areas, 38% of respondents reported taking no personal precaution measures since the beginning of June, 2003 (HSPH, July 2003). Additionally, in high mosquito areas, only 46% of respondents reported having used a DEET-based repellant, 44% removed standing water, 40% avoided going outdoors at peak mosquito hours, and 30% wore protective clothing. Among people living in areas with fewer mosquitoes, only 32% of respondents have taken any precautions against bites (HSPH, July 2003).

Researchers from the Harvard School of Public Health emphasized that it could not be determined from the survey results whether people were taking precautions specifically to protect against WNV or to prevent the annoyance of mosquito bites (HSPH, July, 2003). These survey results indicate, however, that despite the threat of disease transmission and the nuisance posed by biting mosquitoes, many people still are not taking responsibility to protect themselves and their communities.

2.5 Risks & benefits of adulticiding for mosquitoes.

Determining the risk-risk tradeoffs of adulticiding versus not adulticiding for mosquitoes is difficult. In 2001, the New York Department of Health and Mental Hygiene concluded that "the overall risk to human health due to adverse effects from the spraying of adulticides is less significant than health effects due to mosquito-borne infection if adulticides are not sprayed" (cited in Lopez and Miller, 2002). Although many communities and municipalities have agreed with this statement and have supported the use of adulticides, other communities have banned or limited adulticide use for varying reasons. Such reasons include the potential adverse health and/or ecological impacts, the limited efficacy of adulticiding, and/or the belief that other methods of control (e.g., source reduction and education) are more sustainable, efficient, and effective (CCHE, 2002).

2.5.1 Benefits of adulticiding. As mentioned previously, adulticiding can *temporarily* decrease mosquito abundance when applied appropriately. Tietze et al. (1996) determined that an average of 90.2% of adult mosquitoes was killed in a vegetated, residential community during routine truck-mounted ULV applications of malathion. Mosquito mortality may vary depending on targeted mosquito species, degree of resistance, adulticide utilized, equipment utilized, environmental conditions, and physical barriers encountered by the aerosol. In general, however, adulticiding can sufficiently decrease mosquito numbers to allow people to remain outdoors for longer periods of time.

The study performed by Read et al. (1994) demonstrated that the average time of day people went indoors when mosquitoes were present was 7:47 p.m., compared to 8:44 p.m. when mosquitoes were absent. These findings demonstrate that people may remain outdoors an average of 57 minutes longer if mosquito abundance were decreased, thereby enhancing community livability. In addition to these findings, survey results indicated that the frequency of people's outdoor activity typically peaked at 7:00 p.m. on weeknights and declined to near zero at 10:00 p.m. Mosquito activity (in early August) also began at approximately 7:00 p.m. and peaked at approximately 9:30 p.m. (Read et al., 1994). Great overlap occurs, therefore, between the time of evening people spend outdoors and the time when mosquitoes are most active. This overlap emphasizes the importance of controlling mosquitoes to enhance the quality of outdoor activities during the evening hours most commonly enjoyed by people.

2.5.2 Risks of adulticiding. Conversely, the numerous risks associated with adult mosquito control previously reviewed in this paper need to be considered. Adverse human and ecological impacts of ULV adulticiding—although not *typically* common or severe—can occur, especially if applications are not performed correctly or if environmental conditions are not ideal for spraying. Additionally, repeated applications of insecticide would be necessary to have any lasting effect on abundance, as mosquitoes tend to rebound quickly following ULV adulticiding. This repeated application of adulticides may increase risk of human and/or ecological impacts, and would certainly strain a community's resources. Furthermore, the anxiety caused by exposure to pesticides and the belief that other methods of control may be more sustainable and effective can adversely affect community livability for some people. Finally, adulticiding *may* create a false sense of security that limits community participation in source reduction and personal protection activities, thereby potentially increasing risk for mosquito annoyance and/or disease transmission.

2.5.3 Public education of risks/risk analysis. Ultimately, each community must decide which exposure is more threatening to their health and well-being: pesticides or mosquitoes. It is therefore critical for each community member to be well-informed about the risks of his or her exposures. McCarthy et al. (1991) found that 79% of survey respondents received their most useful information about WNV and mosquito avoidance from the media. These findings demonstrate the enormous responsibility for media to provide accurate, consistent, and evidence-based data to the public. Unfortunately, media does not always provide appropriate information to the public.

Roche (2002) examined how effectively North American media communicated with the public in 2000, and found that "the print media were generally ineffective in providing precise information about pesticide risks and in comparing risks of pesticide exposure to those of West Nile encephalitis. The media also were ineffective in mentioning the efficacy of pesticide spraying or comparing the economic costs of pesticide spraying with those of West Nile encephalitis." Access to this kind of information is critical for allowing individuals and communities to make informed decisions about whether to support or oppose adulticiding to combat the mosquitoes that transmit WNV (Roche, 2002).

Roche suggested that public health experts should *actively* (without being approached by a reporter) provide information to the media about the risks and the risk-risk tradeoffs associated with spraying for WNV. This information should be provided with as much precision and accuracy as possible so it is available for reporting to the public (Roche, 2002). Roach ultimately suggested "these efforts could help improve public health by improving decision-making related to the control of insect-borne disease" (2002).

2.5.4 Conclusion. Adulticides may be a useful control measure when surveillance and/or increased resident complaints indicate that mosquitoes have become a severe problem in a community, or when risk of disease transmission is evident. Due to the risks and limitations associated with adulticiding, however, Gubler and Clark (1996) report that community-based, IPM programs that focus on larval source reduction may provide the most cost-effective, sustainable mosquito control over the long term. Utilizing an IPM approach that reserves adulticides for emergency situations may reduce the likelihood of mosquitoes developing resistance, decrease potential health and ecological impacts, and lessen public concerns associated with adulticide use.

Developing responsibility and ownership of mosquito control efforts within a community is essential to organizing an IPM program. To be effective, however, "community organizations at the local level must provide the guidance, leadership, and enforcement of the community standards that govern what is acceptable and what is not acceptable in small geo-political areas" (Gubler & Clark, 1996).

It is also essential to recognize that changing a community's attitudes and behaviors towards mosquito control may take many years to accomplish (Gubler & Clark, 1996). Utilization of interim approaches—such as adulticiding—will therefore "achieve immediate results while preparing the community to assume more responsibility in the long term" (Gubler & Clark, 1996). As the program evolves and matures, increasing emphasis can be placed on community participation in mosquito control, while simultaneously decreasing reliance on adulticiding (Gubler & Clark, 1996). Community-based approaches may maximize the benefits of mosquito control, while minimizing the possible risks associated with adulticiding.

2.6 Summary of Literature Review Findings. Studies have reported both favorable and unfavorable results with regards to the efficacy of ULV adulticide application. Ineffectiveness in adulticiding may be attributed to numerous factors, including differences in choice of adulticide, limitations in adulticide application, inability of adulticides to reduce certain components of vectorial capacity, lack of awareness of the appropriate mosquito species to target, challenges posed by complex mosquito behavior, development of mosquito resistance to certain insecticides, and/or lack of a comprehensive mosquito management program. When applied *appropriately*, however, adulticiding can be effective in decreasing mosquito abundance. While ultra-low volume adulticide applications can help reduce mosquito annoyance, it *may not* effectively interrupt West Nile Virus transmission to humans.

The reasonably anticipated human health impacts of using adulticides for mosquito control are minimal if applications are performed appropriately. When exposure to adulticides from routine ultra-low volume applications occurs, it is not uncommon for minor, temporary, adverse health effects to arise. Such health effects may include skin, respiratory, and eye irritation, among other concerns. *In general,* the amount of insecticide utilized for ultra-low volume applications is not sufficient to cause serious illness in a healthy adult. Serious health outcomes can arise, however, from adulticiding—especially for vulnerable populations. For this reason, it is critical to take special safety precautions when performing ultra-low volume adulticiding to protect the health of all people.

Adverse ecological impacts also can arise from ultra-low volume adulticiding. Although persistence and deposition rates of adulticides in the environment are typically low, some species of terrestrial and aquatic organisms are especially vulnerable to the adulticide aerosols, such as honeybees and aquatic invertebrates. The potential occurrence of adverse ecological impacts emphasizes the necessity of performing ultra-low volume adulticiding as directed by the label. Adhering to labeling laws not only minimizes adverse human and ecological impacts, but also limits the overuse and underuse of adulticides that can lead to mosquito resistance.

Further research is needed to gain an understanding of the cumulative and aggregate effects of chronic, low-dose exposure to insecticides on human health, wildlife, and the environment. It is possible that ultra-low volume adulticiding—although not acutely toxic—may contribute to chronic health and ecological problems.

Quality of human life is impacted by mosquitoes because the presence of adult mosquitoes can trigger feelings of anxiety related to the threat of disease transmission, as well as annoyance related to the discomfort of repeated bites. This annoyance can interfere with community livability, as it often forces people to avoid or limit outdoor activities such as sporting events, social events, barbeques, gardening, exercising, etc. Several studies presented in this paper help to determine the threshold at which mosquitoes are considered a nuisance to humans.

Determining the risk-risk tradeoffs of adulticiding versus not adulticiding in addressing these quality of life/community livability issues is difficult. An adulticide application, in general, is *temporarily* effective in decreasing mosquito abundance when applied according to the directions on the label. Adulticiding can enhance community livability, therefore, by sufficiently decreasing mosquito numbers to allow people to remain outdoors for longer periods of time. Conversely, limitations of adulticiding that adversely affect community livability include the potential adverse health and/or ecological impacts, the anxiety caused by exposure to pesticides, the false sense of security potentially fostered by adulticiding, and the belief that other methods of control may be more sustainable, efficient, and effective. Ultimately, each community must decide which exposure is more threatening to its health and well-being: pesticides or mosquitoes. It is critical, therefore, that each community member is well-informed about the risks of his or her exposures, and is actively engaged in his or her community-based mosquito control program.

Chapter 3-Materials and Methods

As indicated, the objective of this study is to provide a comprehensive review of the risks and benefits of adulticide use in mosquito management efforts. This information will be shared with the Multnomah County Health Department to assist the panel of experts in determining under what circumstances adulticides should be used as part of an IPM program for mosquito control. This information will support a timely, appropriate, and thoroughly reviewed response to WNV if it arrives in Oregon this upcoming mosquito season.

3.1 Methodology. This study is being performed under the guidance of Multnomah County Vector and Nuisance Control and Oregon State University. The study was designed with two major research components, including: 1) an extensive literature review to obtain and compile information related to the efficacy of adulticide use, adverse effects of adulticide use, adverse effects of mosquitoes on community livability, and a risk-benefit analysis of pesticide use; and 2) interviews with selected vector districts to obtain and compile information related to use of adulticides in vector districts around the country. This information helped to develop an understanding of effective and ineffective practices in mosquito management as determined by vector districts that already have confronted WNV.

3.2 Selection Methods. Interviews were performed with vector control agencies within seven states, including Illinois (IL), Colorado (CO), New York (NY), Florida (FL), California (CA), Louisiana (LA), and Texas (TX). New Jersey was initially selected as a state of interest but was not included in the study due to difficulty recruiting a participant from this state. Each of the seven participating states had been exposed to WNV in previous years. Additionally, each state was chosen based on a specific point(s) of interest:

1) Illinois had a well-established vector agency when WNV first appeared in the state. Additionally, Illinois was an epicenter of WNV infection in 2002.

2) Colorado was the epicenter of WNV infection in 2003; they did not have an established vector agency however. Colorado also has a large equine commerce that could be adversely affected by WNV.

3) New York was the first state to encounter WNV.

4) Florida has a well-established vector agency as well as an extensive background dealing with entomological issues.

5) California has both a state vector agency and regional vector districts that are well coordinated. California also has an extensive background dealing with entomological issues.

6) Louisiana has a well established vector agency with a history of adulticide use for mosquito control.

7) Texas has vector districts with urban populations similar in size to Portland based on 2000 census data.

8) New Jersey is home to an extensive vector agency, the American

9) Mosquito Control Association, and an entomology program at Rutgers. Their interest and knowledge regarding adulticide use, therefore, would be informative. Unfortunately, no participant was recruited from New Jersey.

For this study, interviews were performed with individuals working in vector control agencies. Some agencies were selected for an interview based on their decision to utilize adulticides for mosquito control in 2003, while other agencies were selected based on their decision *not* to use adulticides. Individuals interviewed from each state were chosen based on two criteria: 1) personal experience in field work with mosquito management; and 2) the ability to describe how policies related to mosquito control were created in their state or district. The same research questions were asked of all interviewees.

3.3 Research Questions. For the interview portion of this study, the following research questions were developed.

1) What species of mosquito and/or mosquito-borne diseases are the focus of control efforts in your jurisdiction?
2) Please give me a very brief description of your program's overall approach to mosquito control.
3) Did your program use adulticides as part of its mosquito control efforts in 2003?

   If **yes** to 3, can you describe:

   - Why did you make the decision to use adulticides?
   - For how long have adulticides been used in your program?
   - Which adulticides are used in your program?
   - Which adulticides did you use most heavily?
   - What were your reason(s) for selecting these particular adulticides as a suppression method?

4) Has an encephalopathy—particularly WNV—been found in your jurisdiction?

   If **yes** to 4, can you describe:

   - Before the arrival of the encephalopathy, when was the last time you used an adulticide in your jurisdiction?

5) Did you use pre-defined threshold criteria for initiating or continuing use of adulticides during 2003?

   If **yes** to 5, can you describe:

   - What thresholds were used?
   - What process was used to make decisions related to implementation of adulticide use?

6) What methods did you use to measure the success of adulticide use?
7) Do you think that the application of adulticides was successful?

    If **yes** to 7, can you describe:

    - What contributed to this success?

    If **no** to 7, can you describe:

    - What kept the effort from being more successful/what did not work?

8) Did your community have concerns related to pesticide application, disease prevention, presence of mosquitoes, etc?

    If yes to 8, can you describe:

    - What were these concerns?
    - How were these concerns addressed?

3.4 Data Collection and Management. A recruiting call was made to a vector agency that managed WNV in its state during the 2003 mosquito season. Upon identification of an appropriate interviewee, he or she was verbally provided with information regarding the purpose and details of the study, including informed consent. If the participate verbally agreed to participate in the study, the student researcher sent him or her an informed consent letter along with a copy of interview questions in advance of the formal interview. A participant's contact information was kept under lock and key when not in use by the student researcher.

The formal interview was scheduled at the convenience of the participant. The formal phone interview occurred only if the student researcher had received the signed informed consent letter. All seven participants provided their informed consent letter in a timely manner; therefore, no interviews were postponed. The interviews were conducted by the student researcher and were audiotaped and transcribed for analysis.

Interview transcripts were utilized only by the student researcher. After the interviews had been transcribed, all contact information for each participant was physically destroyed. Electronic and hard copies of transcripts were kept under lock and key at all times when not in use by the student researcher or principle investigator. Transcripts contained no identifying information about the participant aside from the state in which he or she worked and his or her job title. Participants' names were not revealed. Additionally, the company, vector district/agency, and/or county a participant worked for were not identified. After the interview transcripts had been analyzed, and case studies had been written, all transcripts were physically destroyed.

3.5 Data Analysis. Descriptive, qualitative data were collected during the interviews. Case studies were created based on each interview performed. In addition to the case studies, qualitative data analysis was performed using a long table approach to extract common and/or important themes from the interviews.

3.6 Risks and Benefits. This research involved no more than minimal risk to the participants. It was possible that the discussion caused individuals in vector districts to think more deeply about their mosquito control efforts. The discussion may have made a participant uncomfortable if he or she did not feel that his or her WNV management practices were optimal and/or effective. Conversely, the discussion also may have benefited participants. Mosquito control efforts for WNV—as well as other vector-borne diseases—may have been enhanced through a detailed discussion regarding current practices.

3.7 Institutional Review Board (IRB) Approval. An IRB was submitted for consideration to Oregon State University on February 9, 2004. IRB approval was received February 25, 2004. IRB approval from Multnomah County was not required because the intent of this project was a formative evaluation to be used in program development for the county health department.

Chapter 4-Results

4.1 Case Studies. A component of this study consisted of interviews performed with individuals working for mosquito control agencies in the United States. Case studies summarizing the findings of each interview are presented below.

4.1.1 Case Study: New York. The state of New York was chosen for this study because it was the first state to be impacted by WNV. Upon the arrival of WNV in 1999, some counties in New York State did not have active mosquito control programs. New York had 70 human cases of WNV and 11 deaths in 2003.

The New York State Health Department provides recommendations related to mosquito control activities. The decision to adulticide, however, is made on a county level in conjunction with local officials.

An interview was performed with an environmental health specialist working for a county in New York. This county did not use adulticides for mosquito control in 2003.

What species of mosquito and/or mosquito-borne diseases are the focus of control efforts in your jurisdiction? WNV is the current disease of concern. In this county, particular species of mosquito are not specified and targeted for control. A great deal of information is available implicating *Culex* as the major species of concern. All mosquito species responsible for the transmission of WNV, however, have not been conclusively identified. Any mosquitoes found breeding in a specified area are controlled, regardless of species.

What is your program's overall approach to mosquito control? When WNV arrived in 1999, aerial spraying was performed over the entire county (except the set-back areas) in response the disease. In 2000 and 2001, truck-mounted spraying was performed in response to WNV while the surveillance program was fine-tuned. The public health education and outreach programs were later expanded. In 2002 and 2003, based on the lack on human cases identified in the county, it was decided that spraying would not be performed unless necessary.

Currently, an integrated approach to mosquito control is utilized. Public health education is a large component of this program with a full-time public educator performing outreach to the public. Consistent contact with local newspapers and radio programs helps to get information to the public about personal protection, source reduction, and surveillance results. Surveillance also is a component of this program. Birds are collected and tested for WNV throughout the year. Two segments of the mosquito populations are trapped using CDC or gravid traps—one segment which is seeking a bloodmeal and one segment which is seeking to lay eggs. Mosquitoes are collected from June through October and submitted for testing for WNV as well as other diseases. Mosquito larvae also are collected and tagged back to treatment sites to get an idea of what mosquito species are present in this county. Larvaciding in waters that are known to breed mosquitoes also is an important component of this program. There are over a thousand open breeding sites that routinely are treated or inspected in this county.

All treatment sites are recorded in a base mapping system. Most of these sites were obtained through complaints from the public when the program was first started, although an aerial flight capturing photographs of the county also helped to identify potential breeding areas. Catch basins in the county also were mapped using GPS receivers. These storm drains were treated with an altosid methoprene product, whereas open breeding areas were typically treated with a BTI product or a close relation to a bacillus sphaericus.

Ultimately, integrated mosquito management programs are very comprehensive, and will require "a lot more manpower than you think it's going to take."

Did your program use adulticides as part of its mosquito control efforts in 2003? Adulticides were not used, primarily because human cases of WNV were not identified in this county.

Has an encephalopathy—particularly West Nile Virus—been found in your jurisdiction? As mentioned, no human cases of WNV occurred in this county. WNV is present in the bird, horse, and mosquito populations.

It is difficult to determine why human cases have not occurred in this county. A great deal of energy is expended on public health education, and the population in this county is careful to take preventative measures—including avoiding the outdoors at dusk and dawn and using repellants. Additionally, mosquito populations are knocked down through the use of larvacides.

Did you have pre-defined threshold criteria for initiating or continuing use of adulticides during 2003? The New York State Heath Department provided guidelines for the use of pesticides in response to WNV. These guidelines help to determine at what threshold the state recommends certain measures be taken.

What process was used to make decisions related to the implementation of adulticide use? In this county, the ultimate decision to use adulticides lies with the Commissioner of Health. The decision is not based solely on whether WNV is present or not, but also on the time of the year. For instance, in the last week of September in New York, the temperature is going to take care of most of the mosquitoes before the adulticide would. Ultimately, the decision to use adulticides is based on the time of the year, the mosquito population status, the dynamics of the population, and what species are present.

Do you think that the application of adulticides would be successful in controlling targeted species? Adulticiding can be successful, depending on the area being sprayed. In order to be successful with truck mounted ULV equipment, a road network that supports sufficient coverage is needed. If adulticiding is performed over a large area with an insufficient road infrastructure, only a small area upwind or downwind of that road will ultimately receive treatment. Aerial applications of adulticide also can be problematic, as there may be limitations based on water bodies around which spraying cannot be performed. It is essential to carefully assess potential treatment sights and determine if effective control is possible. In this county, when effective adulticide coverage was not possible, spraying was not performed. It is a misuse of pesticides because it will not provide the desired results, so why bother doing it?

Conversely, if full-coverage spraying of an area is possible, the adult mosquito population can be quickly knocked down when adulticiding is performed properly. Decreasing the mosquito population would reduce the risk of WNV transmission to humans. It is imperative to note, however, that if adulticiding is not combined with active, ongoing, and effective larvae control and public health education programs, it is not going to work.

What were your community's concerns? A 50/50 split from the public was noted regarding adulticiding—50% wanted spraying and 50% did not want spraying. A phone bank set up prior to and during adulticiding was utilized to address community concerns and questions. Although concerns varied widely, frequently addressed questions included: "Will my children be affected? Will my pets be affected? What do I do with my playground equipment after spraying? Will the pesticide get into our drinking water? Should I close my windows and turn on my air conditioning if I am chemically sensitive? What are the long-term health effects?"

How were these concerns addressed? All questions and concerns were addressed using the phone bank described previously. Additionally, education was provided through public outreach, a website, community presentations, and making information available to the public about the materials used in mosquito control. Educating the community was important because it allowed people to make informed decisions about mosquito control.

Nonetheless, resistance to mosquito control efforts still may be encountered. Ultimately, not everybody is going to be happy with what you do.

4.1.2 Case Study: Texas. The state of Texas was chosen for this study because of the presence of vector districts with populations similar to Multnomah County. Texas had 700 human cases of WNV and 35 deaths in 2003.

In Texas, regional zoonosis control offices perform surveillance activities, while regional environmental health offices perform mosquito control activities (THD, 2003). Although the Texas Department of Health provides guidelines for WNV management (TDH, 2003), individual vector districts are responsible for making decisions about regional mosquito management practices.

An interview was performed with an environmental health specialist working for a county in Texas. This county did not use adulticides for mosquito control in 2003.

What species of mosquito and/or mosquito-borne diseases are the focus of control efforts in your jurisdiction? The primary mosquito controlled is *Culex quinquefasciatus.*

What is your program's overall approach to mosquito control? Until the arrival of WNV, this district had dropped their vector-borne disease control program because the last confirmed human case of encephalitis occurred many years previously. Neighboring counties with well-developed mosquito programs were utilized as benchmarks to determine if any vector-borne diseases were emerging

When WNV arrived, a vector-borne disease control program was reinstated. Surveillance activities were performed using a combination of money from the CDC and bioterrorism infrastructures. State money was used to purchase gravid traps, and one or two traps were provided to each participating city within the jurisdiction. According to pre-arranged schedules, city staff would set out traps, collect the mosquitoes, and drive them to the main office. The main office would process and identify the mosquitoes, and give them to the laboratory for testing. The regional health department laboratory used equipment initially purchased for testing bioterrorism agents to test for WNV in mosquitoes.

Using this system, individual cities exerted minimal time and effort, and the main office did not have to perform any transportation or collection activities. This system resulted in an effective, collaborative, cost-sharing program. Additionally, the regional laboratory provided fast WNV surveillance results (less than three days) in mosquito pools, as compared to the three week turnaround from the state laboratory. This surveillance system helped to identify WNV in various places around the county. To obtain optimal surveillance results, however, it was vital to identify in advance what mosquito species were being looked for and what traps were needed to capture these species. Additionally, surveillance results needed to be carefully documented.

In addition to surveillance, the vector district encouraged individual cities to adopt the following program: "education first, larvaciding if possible, spray if only absolutely necessary." Media releases and mail-outs were provided to the various cities within the jurisdiction for educational purposes, and many cities adopted active larvaciding programs. Ultimately, adulticiding was seen as being the last option. The health department—which oversees the unincorporated part of the county and works in conjunction with all the cities—did not recommend spraying. If a city wanted to spray for political reasons, however, they were permitted.

Did your program use adulticides as part of its mosquito control efforts in 2003?
No spraying was performed at a county level. The county had decided that spraying only would be performed "for a good public health reason." Several cities within the county sprayed, however, for nuisance concerns.

The county decided not to use adulticides for a number of reasons. First, adulticides cause as many difficulties as they cure. About half the people want you to spray and the other half do not. People will complain, "why don't you spray?" or "why are you spraying me?" Whether it is real or not, there is a perceived danger of the random spraying of insecticides into the atmosphere. With low toxicity agents, the danger is not nearly as bad as people think. As a general rule, however, the county does not believe in the random spraying of insecticides, but instead in the strict, targeted use of insecticides.

Second, adulticiding is very expensive. From a sheer resource standpoint, it is difficult to spray on a routine, ongoing basis. Third, the efficacy of adulticiding is reliant on many factors. To be effective, spaying must be performed in a small, targeted area three times in a one week or ten-day period. Furthermore, the spray area must allow for effective treatment on either side of the vehicle (or be done by hand), and the environmental conditions have to be appropriate. For example, in Texas, there may not be three nights in a ten day period where the wind is blowing at less than seven miles-per-hour.

To have an effective adulticiding program, it is not sufficient to spray a neighborhood only one time so the community feels safe. An effective adulticide program requires ongoing control, and the amount of resources needed to do this is somewhat prohibitive.

For how long had adulticides been used in your program? Adulticides were used by the county years ago, although it is not clear for how long they were used.

Which adulticides were used in your program? Scourge was the adulticide of choice; however, the county currently has a 55 gallon drum they are trying to dispose of.

Has an encephalopathy—particularly West Nile Virus—been found in your jurisdiction? Last year, this county had numerous cases of WN encephalopathy.

The adjacent county had more cases of WNV in 2003 despite an active adulticiding program. Although it is a poor use of statistics, there is a distinct correlation between high numbers of human cases of WNV and spraying for mosquitoes. Of course, spraying does not cause mosquitoes. This correlation exists because regions that have always had larger mosquito populations and mosquito-borne diseases have always had to spray.

Before the arrival of the encephalopathy, when was the last time you used an adulticide in your jurisdiction? This county has not had an active adulticide program in several years.

Did you have pre-defined threshold criteria for initiating use of adulticides during 2003? Prior to discontinuing use, if you called your county commissioner and yelled loud enough, the county would spray. It was considered "a vote-getter." Because spraying is an option for mosquito control in this county, threshold criteria were developed. The criteria is a combination of events. It could consist of multiple human cases in a *defined* population area, meaning an area that can be defined as having some commonality. The threshold criteria also could consist of human cases in conjunction with increased WNV activity in the mosquito population *in that same area.* In other words, if surveillance revealed dozens of positive mosquitoes and a human case in that same area, spraying would be performed in that immediate area. In 2003, the criteria were never broached, so spraying did not occur. They human disease cases were scattered throughout the county.

What process was used to make decisions related to the implementation of adulticide use? The CDC guidelines passed down by the state are followed, but with more strict threshold criteria for initiation of adulticiding.

What methods did you use to measure the success of adulticide use? No methods are in place to measure the success of adulticiding in this county because two weeks post-spraying, the mosquitoes will rebound to their original numbers.

Measuring for success of adulticiding, therefore, would "not make a whole lot of difference."

Do you think that the application of adulticides is generally successful? Theoretically, if performed properly, adulticiding can be effective in interrupting disease transmission. It is rarely performed properly, however, for several reasons. First, financial restrictions are always a concern. Second, sufficient trained staff must be available to perform the spraying. Third, environmental conditions must be appropriate for spraying. Finally, adequate resources must be available to routinely spray a specific area.

Adulticiding is analogous to a graph, with the peaks of the graph representing periods of high probability of disease transmission due to large numbers of infected mosquitoes. An *effective* and *properly run* program would knock the tops off of the peaks, but would not eliminate the problem. In the end, adulticiding will lower the probability of disease transmission, but to what extent is unknown.

What were your community's concerns? Many people were concerned about human health impacts related to the spraying of insecticides. Realistically, however, the very low-toxicity adulticides used in most programs will not cause a great deal of problems.

There also were concerns about property damage because old adulticiding products were oil-based and could potentially damage plant life. Some products also could damage painted surfaces, especially if the adulticiding equipment was not working properly. In fairness to the pesticide manufacturers, however, there a number of problems that would not exist if adulticide applicators were consistently careful, picked out the right chemicals, and made sure their equipment was in good condition.

People also were concerned about ecological impacts, such as beneficial insect destruction, as well as pure environmental impacts. Some people—mostly those involved with mosquito control—were concerned about the efficacy of adulticiding compared to the cost.

Conversely, some people were concerned that we were *not* spraying and exposing them to a high risk of the disease. It was therefore essential to educate people that the risk of getting WNV is relatively low. Finally, people also were concerned about general mosquito nuisance.

How were these concerns addressed? Education was provided to ease people's concerns. The media and the internet were utilized as educational tools, and neighborhood association meetings often were attended. Despite this, people still consistently called with questions and concerns, and sufficient time was taken to provide general education over the phone. In terms of nuisance concerns, education was provided to explain that spraying is reserved for known public health reasons. Most people were receptive to this.

It was essential to start education as early as possible about the fact that spraying would be performed *only* for public health reasons, and that adulticiding would not be performed randomly. It was also important to educate people about the actual risk of getting WNV (relative to other risks) to help ease their fears.

4.1.3 Case Study: California. The state of California was chosen for this study because it has both a state vector agency and regional vector districts that are well coordinated. California also has an extensive background dealing with entomological issues and has many mosquito species similar to those found in Oregon. WNV first arrived in California at the end of last year, resulting in three human cases of illness.

The Mosquito and Vector Control Association of California (MVCAC) provides public information, disease surveillance, professional training, and legislative advocacy for mosquito and vector control professionals (MVCAC, 2004). The MVCAC, the California Department of Health Services, and the University of California collaboratively perform surveillance activities in the state (CVDS, 2004). In terms of mosquito control activities, however, most decisions are made by local mosquito control districts.

An interview was performed with an environmental health specialist working for a vector district in California. This district used adulticides in a limited capacity for nuisance mosquito control in 2003.

What species of mosquito and/or mosquito-borne diseases are the focus of control efforts in your jurisdiction? *Culex tarsalis* is the main mosquito vector, although problems also exist with *Psorophora columbiae* and *Aedes vexans*. The major mosquito-borne diseases are SLE, WEE, and WNV.

What is your program's overall approach to mosquito control? The overall approach toward mosquito control is larvacide-based. By using aerial photography and maps from various agencies, complaints, and information received during housing development, sources of mosquito larvae are identified. These sources are placed on a check list and periodically treated during the mosquito season in some parts of the county and throughout the year in other parts of the county. Public education is provided in the form of mailed brochures and/or classes for local schools, service clubs, and scouting organizations. Education, however, is not the focus of control because the vector agency is not large enough to support an extensive educational program.

More personnel have been added to the mosquito control program for this upcoming year. Additionally, a proactive attempt has been made to catalogue as many larval sources as possible "to get an early start" on control activities.

Did your program use adulticides as part of its mosquito control efforts in 2003? Adulticides were utilized in 2003, but only along a river in this county during the latter part of the year. Adulticiding was performed in this particular area of the county because it is very remote and no vector control sub-station exists there. Adulticiding is typically performed in this area one time a week from July to September or October to control floodwater mosquitoes. This agricultural community performs a great deal of crop dusting, so generally people are not too concerned about pesticides or pesticide safety.

For how long have adulticides been used in your program? Adulticiding has probably been performed since the 1980s.

Which adulticides are used in your program? Pyrenone used to be the adulticide of choice; however, Scourge is currently being used.

What were your reason(s) for selecting these particular adulticides as a suppression method? Scourge uses the synthetic pyrethroid resmethrin, which is about half the cost per gallon as Pyrenone—a pure pyrethrin.

Has an encephalopathy—particularly West Nile Virus—been found in your jurisdiction? No encephalopathy occurred in this jurisdiction, although a case of human illness was identified.

Did you use pre-defined threshold criteria for initiating or continuing use of adulticides during 2003? A task force was assembled last year to prepare for the arrival of WNV. This task force utilized a chart designed by the California Department of Health Services to determine the threshold for initiating adulticiding. This chart consists of eight categories that may affect mosquito populations in this area, including: 1) environmental conditions; 2) adult *Culex tarsalis* and *Culex quinquefasciatus* abundance; 3) virus isolation rate in *Culex tarsalis* and *Culex quinquefasciatus* complex mosquitoes; 4) sentinel chicken seroconversion; 5) dead bird infection; 6) equine cases; 7) human cases; and 8) proximity to urban or suburban regions. Each category is graded by a score of 1-5, added together, and averaged. If the average score exceeds a certain threshold, adulticiding would be initiated. A score of 1.0 to 2.5 is considered normal, 2.6 to 4.0 requires emergency planning, and 4.1 to 5.0 is an epidemic.

What process would be used to make decisions related to the implementation of adulticide use? The chart described previously would be used to determine if the threshold criteria had been reached for initiation of adulticides. Approval is then required from the public health officer to perform adulticiding.

What methods do you use to measure the success of adulticide use? Caged vector mosquitoes are placed at predetermined lengths away from the spray head (10 feet, 20 feet, 30 feet, and so forth) in areas where adulticiding is being performed. Following the spray, mosquito counts are performed to determine at which distances adulticiding was effective.

Do you think that the application of adulticides was successful? Larvaciding is a much better process that provides superior control. Adulticiding is a "last-ditch effort" to suppress mosquito populations, but is not as effective as larvaciding. The particular studies performed in this area of California seem to indicate that because of the foliage being sprayed, the barriers the mist encounters, weather factors, temperature factors, etc., conditions are seldom ideal for adulticiding. These studies seem to indicate that at most, 10-20% effectiveness in mosquito kills is achieved. Although this is only an estimate, it simply seems that an extensive larvacide program is more effective than adulticiding.

In the areas where mosquito problems were identified, physical alterations were performed (as able) to reduce the larval habitat, which was followed by regular larvaciding. This approach resulted in large decreases of mosquito populations and mosquito-related complaints. Adulticiding may be immediately effective, but mosquito-related complaints will quickly return. If adulticiding were performed every single day, it may be a more effective treatment option; however, daily adulticiding would be cost-prohibitive.

What were your community's concerns? Nuisance mosquitoes were a concern along the river; however, as discussed, adulticiding was performed in this area.

The media in this area was extremely active in providing information to the public. Community members familiar with WNV were very concerned; especially the elderly that are most affected by the disease. Additionally, most horse owners were concerned, especially those who had not vaccinated their horses.

Concerns about pesticide use were more common in areas of the county where people were not accustomed to pesticide exposure. As discussed, in agricultural areas, people generally were less concerned. Adulticiding was performed in one area along the river where numerous elderly people lived, and those communities seemed more concerned than others. In places where pesticide exposure was less frequent, environmental groups raised concerns about the possibility of insecticides causing cancer and other various health problems.

In this area of California, a situation like WNV has never happened before. It will be interesting to see if increasing cases of WNV will prompt people to set aside their concerns about pesticides because of an obvious health threat, or if people will think that exposure to adulticides is just as bad as exposure to WNV.

How were these concerns addressed? Concerns were addressed by providing education about adulticides and WNV. In terms of adulticiding, people were informed that no adverse health effects are associated with Scourge and Pyrenone in the concentrations used for adulticiding. Exposure to these adulticides is very minute, and only sensitive people with allergies might experience a problem. People also were informed that studies performed on these adulticides revealed no deleterious effects to people, their animals, or anything else. Additionally, research studies, adulticide labels, and appropriate information from the internet were provided to people to help answer questions or ease concerns. Usually, this kind of educational approach was effective.

4.1.4 Case Study: Florida. The state of Florida was chosen for this study because it has a well established vector agency as well as an extensive background dealing with entomological issues. In 2003, Florida had 93 human cases of WNV and six deaths.

In Florida, the Department of Agriculture and Consumer Services works with local mosquito control districts to provide the public with information about mosquito control operations in areas where arboviruses are found, respond to requests for mosquito control in areas lacking mosquito control programs, and release public information regarding animal health issues and protective measures (FDACS, 2003). Local mosquito districts, however, generally are provided the authority to make decisions related to mosquito control for their region.

Additionally, the Florida Mosquito Control Organization, first established in 1922, is a non-profit, technical, scientific and educational association of mosquito control for all people interested in the biology or control of mosquitoes or other arthropods of public health importance (FMCO, 2004).

An interview was performed with a manager working for a local mosquito control district in Florida. This district used adulticides for mosquito control in 2003.

What species of mosquito and/or mosquito-borne diseases are the focus of control efforts in your jurisdiction? The main mosquito that transmits both WNV and SLE is *Culex nigripalpus.* This mosquito can reproduce in almost any kind of standing water, from containers to brackish water. It persists in the warm weather almost all year long. In addition to *Culex nigripalpus*, there may be other vector species for WNV that have not yet been identified.

In terms of nuisance mosquitoes, *Mansonia dyari* and *Mansonia tittilans*—which attach to the roots of aquatic plants—are often a concern even when rainfall is scarce. Floodwater mosquito species *Ochlerotatus atlanticus* are a minor nuisance in this area, while *Psorophora columbiae* tend to be a more significant problem. Some treatment in this area also is done for *Anopheles* mosquitoes.

What is your program's overall approach to mosquito control? Integrated pest management is utilized to *prevent* mosquitoes as much as possible through either modifying their habitats or preventing construction of their habitats. A public campaign is utilized to eliminate container mosquitoes *Aedes albopictus* and *Aedes aegypti* which accounts for 10% of service calls. Gambuzio fish—native to Florida—also are put out as predators. BTI's and larvacides are used to the extent possible, and above-ground spraying of adulticides is performed only as a last resort.

Larvaciding against the saltwater/floodwater mosquitoes has been very successful. Precision targeting and GIS mapping of the major productive sites has been performed, and identified breeding sites are either pre-treated with a larvacide or monitored closely for larvae emergence. Adulticiding is still necessary in many areas, especially in rural communities where many people live on large plots with floodwater mosquitoes.

Virus monitoring also is a large component of the program. WNV is likely endemic in Florida now, and transmission can occur any time of the year because of the warm weather. Viral surveillance, therefore, is critical. Sentinel chickens and collected mosquito pools are used to detect virus activity in the area.

With regard to education, a full time employee performs outreach to the community. Container abatement programs also are utilized to encourage citizens to actively reduce sources of mosquitoes around their homes.

Did your program use adulticides as part of its mosquito control efforts in 2003? Adulticiding was performed in 2003 to control mosquitoes.

For how long have adulticides been used in your program? Adulticides have been used by this program since the 1940s. Adulticiding has been essential in Florida because there are so many mosquitoes.

Which adulticides are used in your program? A material called dibrom (naled) is currently used. Although naled has a moderately toxic label, it dissipates from the environment in a matter of three or four hours after it is applied. Naled is aerially applied at night. Biomist is used for truck-mounted adulticide applications.

What were your reason(s) for selecting these particular adulticides as a suppression method? The quick breakdown of these adulticides is significant because they are not persistent in the environment. These adulticides are generally more expensive than malathion; however, malathion tends to persist longer in the environment and resistance has been noted in some local mosquito species. Additionally, these adulticides are effective and quick.

Has an encephalopathy—particularly West Nile Virus—been found in your jurisdiction? Confirmed cases of WNV and SLE have occurred in recent years.

Before the arrival of the encephalopathy, when was the last time you used an adulticide in your jurisdiction? As mentioned, adulticiding has been used in this program for years. SLE has been in Florida since 1964, so adulticiding has been important for disease control. Additionally, before an extensive larvaciding program was initiated, adulticiding was performed to control nuisance (floodwater/saltwater) mosquitoes.

Did you use pre-defined threshold criteria for initiating or continuing use of adulticides during 2003? The criteria written in the Florida statutes mandates that the presence of at least 25 mosquitoes captured overnight in the light trap are required to initiate adulticiding. Generally, these mosquito numbers can be captured any given night, except for some nights in January or February. Of course, spraying does not occur every night that 25 or more mosquitoes are trapped. A combination of things are taken into consideration, such as weather. In cooler weather, people wear more clothing and are less likely to be bitten. Adulticiding is performed minimally from November to May, therefore, due to decreased risk of being bitten by a mosquito. Additionally, there is a range of tolerance among the citizens, and the threshold to trigger adulticiding is not the same in every zone. For instance, heavily populated, elderly communities in particular parts of the county will tolerate less mosquito nuisance than other populations living in rural areas.

In general, more treatments are directed at nuisance species than at vector species because it is difficult to focus efforts on the vector species. Viral transmission can occur any time of the year, and a good target to spray is rarely available. In 2003, every sentinel chicken site eventually became positive for WNV, making it difficult to determine viral "hot-spots." Positive mosquito pools generally were helpful in determining what mosquito species to target—such as *Culex nigripalpus*. As mentioned, however, it appears that other mosquito species are involved in the transmission if WNV, because transmission continues to occur when the known vector *nigrapalpus* is present in very low numbers, thus complicating targeted adulticiding efforts.

In general, the basic criterion to initiate adulticiding is mosquito abundance and/or viral activity sufficient enough that adulticiding would make a difference. Additionally, large numbers of service requests from individuals can trigger adulticiding. Prior to the application of any pesticides, however, it is necessary to document the mosquito numbers present in a specific treatment area.

What process was used to make decisions related to the implementation of adulticide use? The only situation where permission to use adulticides is required is in state designated lands—such as state parks. In this situation, permission from land resource people—such as the Bureau of Entomology and the Department of Agriculture—is required prior to adulticiding. Spraying only would be performed in these areas, however, if there were a declared medical alert and the demonstrated presence of mosquitoes. Although the state parks are monitored, they are normally not sprayed.

What methods did you use to measure the success of adulticide use? Pre- and post-spray trappings are utilized to demonstrate the effectiveness of adulticiding.

Do you think that the application of adulticides was successful? For nuisance mosquitoes, adulticiding is definitely effective. Reductions based on the pre- and post-trapping of 95-99% have been demonstrated. The lowest efficacy rate from adulticide applications has been around 75%.

Efficacy is more difficult to quantify in terms of disease transmission. Comparing the number of WNV cases that have occurred in the state of Florida with the number of WNV cases that have occurred in this county demonstrates the efficacy of mosquito control efforts in this area. Of course, the risk of disease transmission cannot be reduced to zero by mosquito control efforts, so it is necessary to take individual precautions.

Success can be attributed in part to timing. Adulticiding was performed during the peak hours when large numbers of mosquitoes were exposed. Additionally, naled is a very effective adulticide.

What were your community's concerns? Occasionally, individuals wanted to be called before spraying occurred, and this request was accommodated. A long list of people who have requested to be pre-notified exists in this county.

Additionally, many years ago, an adulticiding plane accidentally flew over a group of people who looked up as the plane flew by and later experienced burning eyes. Numerous phone calls were received about this incident. These kinds of things can happen, so great care must be extended to avoid adverse situations.

Otherwise, few consumer complaints have been received about the spraying. Nobody has been identified as being affected toxically. For the chemically sensitive people, it was essential to provide advance notice if spraying was going to occur. Additionally, a designated "no spray" zone was created where adulticide trucks turned off their spray systems a block before they arrived at the homes of chemically sensitive people, and turned them back on a block after they passed.

WNV is relatively new, but has received a great deal of press coverage. Many people, therefore, were very concerned about the presence of mosquitoes last year.

Occasionally, if a resident noticed or was bitten by a single mosquito, they would call and ask "What should do? Do I need to see my physician?"

How were these concerns addressed? In terms of disease prevention, people wanted to know what they could do to protect themselves. Education was provided in a proactive way to help answer people's questions. Rather than waiting for people to call, employees went out to the communities and talked to homeowners associations, schools, and people at the county fair to provide information. Literature—translated into several different languages—also was handed out as an educational tool.

Presentations also were provided to an anti-pesticide group to promote a good working relationship with the mosquito control district. The concerns of this group were addressed, and they were ensured that the least toxic approach to adulticiding was being used. This direct communication allowed a good relationship to be developed with the people most concerned about chemical safety in this area. To date, there has not been a demand that spraying not be performed for any reason.

4.1.5 Case Study: Louisiana. The state of Louisiana was chosen for this study because it has an established vector control agency with a history of adulticide use for mosquito control. In 2003, Louisiana had 123 human cases of WNV and 8 deaths.

The Louisiana Mosquito Control Association (LMCA), first established in 1957, serves as a source of information, continuing education, and technical support for mosquito control professionals in Louisiana.

Local mosquito control districts—often referred to as parishes—are responsible for making decisions related to mosquito control. Currently, 21 districts are members of the LMCA and provide mosquito control services in Louisiana. Additionally, some districts have local mosquito control agencies. Many other districts, however, have limited or no mosquito control services available (LMCA, 2004).

An interview was performed with an entomologist working for a parish in Louisiana. This parish used adulticides for mosquito control in 2003.

What species of mosquito and/or mosquito-borne diseases are the focus of control efforts in your jurisdiction? Approximately 45 species of mosquitoes exist in this area, 15 of which are vectors of mosquito-borne diseases. The most important species in terms of disease control are *Culex pipiens* and *Culex quinquefasciatus*. Four mosquito-borne diseases are controlled, including LaCross encephalitis, EEE, SLE, and WNV.

What is your program's overall approach to mosquito control? The program is responsible for both disease surveillance/control and pest control and consists of several components. First, mapping and inspection of treatment areas is performed.

Second, surveillance activities are utilized to monitor rainfall, mosquito abundance, and virus activity. Rainfall is monitored in treatment areas using rain gauges, and light traps are used to collect both vector and/or pest mosquitoes. Vector mosquitoes are submitted for processing. Approximately 50 light traps are permanently stationed around the parish to monitor mosquito population levels as well as the species of mosquito coming to the light traps. Portable light traps also are utilized to monitor specific situations of concern. For example, if a great deal of rainfall occurred in a certain part of the parish, portable light traps enhanced with carbon dioxide would be used to collect mosquitoes for virus surveillance. Additionally, gravid traps are used to collect *Culex* mosquitoes for virus surveillance.

Third, source reduction is performed where possible, although this is less frequent now due to wetland restrictions. Of course, public education in terms of source reduction is critical for mosquito control. The southern house mosquito breeds readily in water-filled containers around people's homes, as does the Asian Tiger mosquito—a vector of both WNV and EEE in this area. If the citizen calls with a service request, an inspector goes to the area of concern to determine what kind of mosquito is causing the nuisance. If it is the southern house mosquito or the Asian Tiger mosquito, the inspector will look around the property, empty containers that are holding water, and encourage the property owner to continue emptying these water sources on a regular basis. If there is a large adult mosquito population in a limited area, the inspector may perform hand fogging.

In terms of education, the media provides a number of opportunities for mosquito control professionals to appear on television, the radio, and in newspapers. Additionally, commercial containing public service information was designed and shown on television during critical parts of the year. Finally, a 20-minute program developed by the county aired regularly on cable television to provide further education to the public.

Additionally, education also is provided to the local schools. Mosquito kits—complete with mosquito eggs—are provided to participating classrooms. Children submerse the mosquito eggs in water, and eventually watch the eggs hatch. Once the mosquitoes emerge, the children are able to observe them over the course of a week or two, depending on the length of their life cycle. The teacher can build this program into the classroom curriculum, helping to educate children about mosquitoes and mosquito-borne diseases.

Two full time teachers also work with the vector control district on a part-time basis in the summer to provide education to daycare centers. If transportation is available, children from local daycare centers visit the mosquito control facility for an educational field trip. If transportation is not available, teachers travel to the daycare centers to provide education. As part of the educational program, the teachers supply each child with a mosquito control "check list" to take home to their families. The child, along with his or her family, performs an inspection around their home. The child then returns the completed "checklist" (with an adults' signature) to the daycare staff to receive a small award for participating in this activity.

Fourth, larvaciding with bio-pesticides is performed extensively, with thousands of acres larvacided last year.

Finally, aerial or ground-applied adulticiding is performed.

Did your program use adulticides as part of its mosquito control efforts in 2003?
Adulticides were utilized in 2003 for several reasons. First, adulticiding was performed to control some of the pest mosquito species in the wooded areas where larvaciding was not feasible. *Many* acres of forested area exist that cannot be larvacided because of the location or wetland restrictions that prohibit draining. Adulticiding was therefore performed to create a buffer between the mosquito source and the human population. Second, during the course of virus surveillance last year, numerous mosquito-borne diseases were detected. Both larvaciding and

adulticiding activities were performed in response to the presence of these viruses. Once the viruses had reached the adult mosquito population, the only effective way to break the cycle was to kill those infected mosquitoes through adulticiding.

For how long have adulticides been used in your program? Adulticides have been used since the 1970s.

Which adulticides are used in your program? Resmethrin is primarily used in for truck-mounted adulticiding, and naled is used for aerial applications. Anvil is occasionally used, but not as frequently as resmethrin and naled.

What were your reason(s) for selecting these particular adulticides as a suppression method? The program initially used malathion; however, resistance to this adulticide began to develop, especially in the *Culex quinquefasciatus* populations. Resmethrin and naled were therefore chosen as good alternatives. The application rate with naled is very low, ranging from 0.5 ounces per acre up to 1.0 ounces per acre so you can cover a very large area quickly. Additionally, naled has a very short half life in the environment and dissipates quickly. The resmethrin was a good choice for ground units because it provides a quick knock-down of mosquito populations and is environmentally safe. No significant impacts, either human or ecological, have resulted from the use of either of these materials in this program.

Has an encephalopathy—particularly West Nile Virus—been found in your jurisdiction? Yes, both WNV and SLE have been found.

Before the arrival of the encephalopathy, when was the last time you used an adulticide in your jurisdiction? This district was created in response to the economic impact of mosquitoes on the area and a history of SLE. Adulticiding has been a component of mosquito control from the very beginning, and was a vital part of the program in 1999 when a very large epidemic of EEE occurred in the state.

Did you use pre-defined threshold criteria for initiating or continuing use of adulticides during 2003? Yes and no, depending on the species of mosquito being controlled. There are tons of pest mosquitoes, and threshold levels vary among regions and time of the year. For example, the northern floodwater mosquito is a cool weather mosquito. In the fall and winter when people are wearing heavier clothes, mosquitoes are less of a nuisance. In the summertime, however, when people are outside in their shorts, the same number of summertime species *Psorophora columbiae* can easily result in a nuisance problem. A nuisance threshold exists, but it varies by species, time of year, and area of the community of concern. For example, *Psorophora ferox* is a very aggressive mosquito and under the best of circumstances, one or two of these mosquitoes per minute constitutes a control issue. Additionally, people in urban areas generally are less tolerant of mosquitoes than those in the rural areas. Decisions are made everyday based on these types of considerations.

In terms of vector mosquitoes, if virus activity is identified in an area, larvaciding and adulticiding subsequently will be performed. It may be in a storm drain, under homes, or any number of areas.

In terms of floodwater mosquitoes, these species have eggs that hatch in a very short time period after a rain event or flood event. The control activities will be quite intense, therefore, but over a short period of time.

The *Culex* mosquito, on the other hand, has an asynchronous life cycle. When this mosquito species is involved in disease transmission, therefore, control measures become much greater. *Culex* mosquitoes are produced throughout the day, every day, and in a variety of habitats, including water-filled containers in people's backyards, underground storm drains, roadside ditches, and any other area that contains organic matter. If the *Culex* mosquito hatches today, she generally will rest for a day or so prior to seeking a bloodmeal. If spraying is performed at that point with an adulticide, she can be controlled. If you miss that day, she again hides under homes, in storm drains, and other inaccessible locations for a couple of days to digest her bloodmeal. Then, she goes out to lay her eggs and again she is susceptible to treatment with adulticides. Ultimately, with the *Culex* mosquito, an area needs to be treated with adulticides (in general) on three successive nights in order to break the disease transmission cycle. Otherwise, at least a third of the mosquitoes are going to be resting somewhere and not exposed to the insecticide.

What process was used to make decisions related to the implementation of adulticide use? Decisions about adulticiding are made independently on a county level based on surveillance activities for both pest and vector mosquitoes. In addition to collecting mosquitoes for disease surveillance, sentinel chickens are used and wild birds are collected and bled for virus surveillance. All of these components are involved in the decision-making process, but permission is not explicitly required from anyone to initiate adulticiding.

What methods did you use to measure the success of adulticide use? Several different methods are used to measure the success of adulticide use. For pest mosquitoes, pre- and post-treatment landing rate counts are utilized, which requires counting the number of mosquitoes coming to feed on someone before and after spraying. A cage test also is used, where caged mosquitoes are placed in the spraying area to determine mosquito mortality. Additionally, equipment and insecticides are routinely checked for accuracy. Droplet tests are performed to ensure the correct droplet size is being dispensed, and cage tests are performed in relatively open areas to ensure all systems are operating properly. Finally, bottle bioassay tests are performed to determine if any resistance is detected in the mosquitoes to the insecticide being used.

Do you think that the application of adulticides was successful? In 2002, a great deal of adulticiding was performed in response to the WNV epidemic; however, numerous human cases of WNV were identified, along with over 30 positive pools of mosquitoes.

By 2003, more had been learned about WNV, surveillance efforts were refined, and treatments were more target-specific, although adulticiding still was a very important part of mosquito control. In 2003, less than five human cases of mosquito-borne diseases were identified, despite having identified over 100 pools of positive mosquitoes.

The incidence rate of WNV in this parish was significantly higher in 2002 compared to 2003, when control efforts were refined. Additionally, a parish in a region similar to the parish under study *did not have a mosquito control program* in 2003, resulting in a significantly higher incidence rate of disease.

Additionally, this county vector district was able to document success in controlling the targeted species. Several sights in the county were problematic last year in terms of WNV in *Culex* mosquitoes. When virus was detected in those areas, control strategies would be initiated, including larvaciding and adulticiding. Continual monitoring would be performed at these sights, and in most situations, the disease cycle was broken for at least two to three weeks after initiating one *course* of adulticiding in that area. In a couple of locations, control activities had to be performed twice to break the disease cycle. In general, however, positive mosquitoes were detected, control activities were initiated, and continued sampling at that sight showed that even though mosquitoes were present, the virus was no longer there.

Success can be attributed to having a comprehensive program that locates breeding sites, keeps pressure on mosquito populations throughout the year through larvaciding, performs good surveillance to detect virus activity, and initiates adulticiding in the areas where the virus is present.

In terms of larvaciding, locating the breeding sites of *Culex* mosquitoes was extremely difficult because many of these sites were cryptic and difficult to find. In terms of adulticiding, because the *Culex* mosquito does not fly very far (generally their flight range is a mile or less), treatments were performed fairly intensively (aerially and by truck) within a one mile area of a viral "hot spot" for three evenings. Control activities would then be expanded approximately one mile around this center with spray trucks. Although this approach required more adulticiding than what generally is preferred, it seemed to be very successful and was absolutely essential because of the asynchrony of the *Culex* lifecycle.

What were your community's concerns? In Louisiana, the public tends to approve of mosquito control programs. More comments were received concerning "why weren't you there," instead of "we don't want you there." There were less than 20 people on the "no spray" list in this parish. Some people did not favor spraying because they have an allergic response to the material or because they have bees on their property that adulticides may harm. Some people simply did not favor spraying. In general, however, the public was very accepting of the program.

The biggest problem encountered in the last few years deals with bio-terrorism. People have wanted reassurance that the low-flying aircraft seen during adulticiding was not a terrorist aircraft. Although most of the residents in the parish are familiar with the adulticiding aircraft, occasionally someone has called with concerns. A system was developed with local 911 responders, the sheriff's dispatch, and the airport control tower. Each of these services was given advance notice of adulticiding schedules so if they received a call from a citizen, they would know whether adulticiding was scheduled to occur.

People also were concerned about WNV, which impacted the community greatly in 2002. There was a good deal of publicity about WNV, and people were aware that the disease did not always resolve quickly. In certain cases, WNV has similar effects as polio, with many survivors continuing to have serious problems long after the acute onset of the disease. Most of the people in this community have been touched by EEE, SLE, or WNV in some way over the years, which compounds their concerns about mosquito-borne disease.

How were these concerns addressed? In terms of addressing concerns, as much information as possible was provided about WNV and mosquito control activities. Public education was a large component of this program, as described previously.

Additionally, if people did not want spraying performed in a particular area, an attempt was made to turn off adulticiding machines in that area. Similarly, if joggers or other people with particular exposures were identified during spraying, the machine was turned off and adulticiding was attempted at a later time.

4.1.6 Case Study: Illinois. The state of Illinois was chosen for this study because of the extent to which the state was impacted by WNV in 2002, as well as the apparent success of mosquito control efforts in 2003. Illinois had 884 human cases of WNV and 64 deaths in 2002, and 54 cases of WNV and one death in 2003.

The Illinois Department of Agriculture regulates mosquito control, providing very general guidelines to be followed by the vector districts (IDA, 2004). The Illinois Department of Public Health maintains a sophisticated surveillance system (IDPH, 2004). It is the responsibility of the regional vector districts to make decisions about pest management and to perform mosquito control activities.

An interview was performed with a biologist working for a vector control district in Illinois. This district used adulticides for mosquito control in 2003.

What species of mosquito and/or mosquito-borne diseases are the focus of control efforts in your jurisdiction? In the vector district of Illinois under study, there are over 40 different species of mosquito to control, although certain species dominate control efforts. The primary nuisance species are *Aedes Vexans*, along with related species including *Ochlerotatus trivittatus* and *Ochlerotatus sticticus.* The primary vector species are the *Culex* complex, including *C. pipiens* and *C. restuans*. The main mosquito-borne diseases include SLE and WNV.

What is your program's overall approach to mosquito control? The program's approach to mosquito control is integrated, with components including surveillance, information distribution, larval control, and adult mosquito control.

Surveillance activities include weather surveillance (rainfall, temperature, and depth poles), adult mosquito surveillance (light traps and ovi-position traps), larva surveillance, and vector surveillance (dipstick tests for WNV and gravid traps).

Information distribution consists of pamphlets and presentations provided to residents and homeowners, maps of mosquito breeding sources provided to communities, and press releases provided to the news media.

Larval control is the primary focus of district efforts and consists of treating catch basins, off-road basins, and general larval areas, performing source reduction, and distributing predator fish.

Adult mosquito control is considered supplemental to larvacide control. Some acreage within this district consists of open fields and wooded areas where mosquitoes harbor during the day. These areas are treated with adulticides in the early morning to control for both nuisance and vector mosquitoes when surveillance indicates that mosquito populations are high. Although these areas represent a very limited acreage, adulticiding improves the quality of life for homeowners living there. Many forest preserves, however, do not allow adulticiding within their boundaries because they are mandated to "protect the flora and fauna," and adulticides kill more than just mosquitoes. Only larval control is utilized, therefore, in these forest preserves. In residential areas, larvaciding is also the primary means of mosquito control. Prior to the arrival of WNV, adulticides had not been used in a residential area since the 1980s.

Did your program use adulticides as part of its mosquito control efforts in 2003?
In 2003, adulticides were used in localized areas that were demonstrating increased WNV activity in the mosquito population.

For how long have adulticides been used in your program? The vector district under study has been well-established for many decades; however, it is unclear how long adulticides have been utilized. Prior to the 1980s, adulticide spraying was performed on an "as needed" basis to control nuisance mosquitoes. In the mid-1980s, however, it was determined that adulticiding was not sufficiently controlling nuisance mosquitoes and should be utilized only when potential disease transmission was evident.

Which adulticides are used in your program? The adulticide of choice is Anvil 10+10 ULV.

What were your reason(s) for selecting these particular adulticides as a suppression method? Anvil 10+10 ULV was chosen based on public acceptance and the perception that it is the safest. Additionally, this adulticide is cost-efficient and locally available.

Has an encephalopathy—particularly West Nile Virus—been found in your jurisdiction? A WNV encephalopathy has been found within this district.

Before the arrival of the encephalopathy, when was the last time you used an adulticide in your jurisdiction? As stated, prior to the arrival of WNV in 2002, this district had not performed any residential adulticiding since the 1980s.

Did you use pre-defined threshold criteria for initiating or continuing use of adulticides during 2003? The primary triggers for initiating adult mosquito control in this district include: 1) positive mosquito pools; 2) dead birds/positive bird blood; 3) surrounding state data indicating viral activity (particularly early in the season); 4) time of season (*initial* positive birds and mosquitoes confirmed early in the season); 5) positive equine cases; and/or 6) positive human cases.

Secondary triggers to initiate adulticiding include: 1) a vector population level larger than normal (which poses a greater risk for spillover disease transmission to humans); and/or 2) favorable climactic conditions (above normal temperatures or rainfall levels).

What thresholds were used? The primary threshold used in 2003 was the presence of mosquito pools that tested positive for WNV or SLE. Gravid traps in localized areas captured mosquitoes with a much higher level of virus compared to the other parts of the district, and these areas were subsequently sprayed. It was imperative, however, to consider "the whole picture" when making decisions about mosquito control.

What process was used to make decisions related to the implementation of adulticide use? The threshold criteria set up by the district was thoroughly reviewed. If threshold criteria were met, spraying would occur only if weather conditions permitted. According to the licensing system in Illinois and the structure of mosquito districts, decisions about adulticiding are made by each individual vector district. Loose regulations set up by the state allow each vector district to make their own decisions related to mosquito control.

What methods did you use to measure the success of adulticide use? In general, pre- versus post-trap mosquito count inspections were utilized. Typically, this type of measurement does not provide enough data points to get statistically significant information. Obtaining good statistical results to measure the success of adulticiding is difficult because mosquitoes are free-flying and multiple factors can affect a trap count from day to day. Long-term studies, however, show that when proper procedures are followed, a certain level of control will be achieved.

Do you think that the application of adulticides was successful? In 2003, adulticiding was considered "as successful as adulticiding can be." In terms of the areas sprayed, a 20-30% reduction in mosquitoes was generally considered effective.

What were your community's concerns? Concerns varied widely among different communities. One of the biggest concerns in this district was providing pre-notification of spraying. Different communities wanted to be notified in different ways, and occasionally pre-notification was not possible because appropriate weather conditions for spraying were not predictable. Generally, however, people were notified in advance that virus activity had increased in their neighborhood and that adulticiding was necessary within the week.

Additionally, there were concerns about the presence of mosquitoes. Mosquito complaints were recorded and monitored, and numerous complaints in a specific area generally triggered a targeted mosquito surveillance investigation. Decisions about mosquito control, however, were not based solely on complaints about mosquito nuisance, which tended to be driven by varying factors. For example, phone calls about mosquito nuisance increase every year when property tax statements are issued because mosquito abatement is listed as a tax amenity. Mosquito abundance is not actually increased, but people are reminded of mosquito control services. Additionally, people tend to have different levels of comfort. Some people call if they receive one mosquito bite in an evening.

A final concern commonly verbalized by community residents was the use of pesticides in mosquito control. Because adulticides are spread over an area that people may come in contact with, there were frequent concerns about the effects of adulticiding.

How were these concerns addressed? To address community concerns, people were generally provided with information from the mosquito control district or an outside agency. Because people may inherently distrust mosquito abatement employees, community members were often referred to external resources, such as the Illinois Department of Health, who addressed concerns as an impartial third party.

4.1.7 Case Study: Colorado. The state of Colorado was chosen for this study because of the extent to which the state was impacted by WNV in 2003. Colorado had 2477 human cases of WNV and 45 deaths in 2003. Colorado also has a large equine commerce that could be adversely affected by WNV.

Environmental conditions, including high levels of rainfall and high summer temperatures, created ideal conditions for mosquito breeding and disease transmission in 2003. Additionally, populations of vector mosquitoes were identified three to four weeks earlier than what would be considered normal, which compounded the effects of WNV.

Furthermore, the structure of mosquito control in Colorado is interesting because certain jurisdictions have their own government-operated mosquito control units, either within the health department or public works department. Other jurisdictions, however, contact the services of a professional company to perform mosquito control activities.

An interview was performed with a biologist working for a professional contract company in Colorado. This contract company used adulticides for mosquito control in 2003.

What species of mosquito and/or mosquito-borne diseases are the focus of control efforts in your jurisdiction? The species of mosquito being controlled include the *Culex* species, specifically *C. tarsalis, C. pipiens*, and *C. Ulnaris*. The primary diseases being controlled are WNV, SLE, and WEE.

What is your program's overall approach to mosquito control? Most contracts include larval control and surveillance activities along with a small amount of adulticiding. The main focus is larval control, which includes intensive mapping of breeding and developmental sites such as flood irrigation sites, ditches, cattail marshes, and catch basins. Technicians go out to each mapped site on a weekly basis to inspect for mosquito larvae and perform larval control activities as needed. Additionally, adult mosquito surveillance is performed using extensive trap networks. If surveillance indicates that adult mosquito numbers are increased in a certain area, adulticiding will be performed. Generally, the local health departments are responsible for providing education about mosquito control and personal protection. Health departments also are responsible for avian and human surveillance programs.

Did your program use adulticides as part of its mosquito control efforts in 2003? Adulticides were used for mosquito control in 2003. It was important to control disease vectors since WNV was so predominant in Colorado last year. Additionally, adulticiding was performed to control nuisance mosquitoes to allow people to live more comfortably. This area of Colorado has many people that are active in the outdoors; therefore, people are generally happy when control efforts result in decreased mosquito abundance.

For how long have adulticides been used in your program? The length of time that adulticides have been used varies according to the contract.

Which adulticides are used in your program? The primary adulticide of choice is Biomist 3+15.

What were your reason(s) for selecting these particular adulticides as a suppression method? Biomist 3+15 is relatively safe to use. It has efficient and effective knockdown rates of adult mosquitoes, as well as a fast breakdown time in the environment. This adulticide photo-degrades generally within 24 hours.

Has an encephalopathy—particularly West Nile Virus—been found in your jurisdiction? An encephalopathy has been found in this jurisdiction.

Before the arrival of the encephalopathy, when was the last time you used an adulticide in your jurisdiction? Prior to the arrival of WNV, adulticiding had been performed to control nuisance species. Additionally, there had been occasional, small increases in other encephalitis'.

Did you use pre-defined threshold criteria for initiating or continuing use of adulticides during 2003? Generally, the threshold used as a general indicator of relative nuisance is 100 females in a trap for any given trap night. Input from the residents and government officials of the contracted municipalities and counties also is considered.

What process was used to make decisions related to the implementation of adulticide use? Each municipality and county government contracting with this mosquito control company dictates the extent of adulticiding performed in their jurisdiction. Large-scale spraying over entire communities often requires permission from local government agencies. Although it may vary according to the contract, adulticiding generally can be performed in a specific neighborhood without explicit approval if deemed necessary by the contracted mosquito control company. In certain areas, however, it may be required to provide pre-notification of spraying in the local newspaper.

Additionally, this company adheres to the laws and regulations set forth by Colorado's Department of Agriculture, as well as the recommendations provided by the Colorado Health Department and the CDC.

What methods did you use to measure the success of adulticide use? Pre- and post-spray trappings are performed to measure the success of adulticide use. Post-spray trappings are performed the day after adulticiding is performed.

Do you think that the application of adulticides was successful? Fairly good results (approximately 90% reduction in post spray traps) have been obtained following adulticide use. Setting pre- and post-spray traps has made it quite evident that spraying was effective.

Several valuable lessons were learned in 2003 that will help improve control efforts next year. First, approval to perform community-wide adulticiding from city councils and health departments took longer than expected last year because of financial and political reasons. Spraying could have been more effective if it was performed three weeks earlier at the peak of transmission. This year, surveillance data will be analyzed more closely and compared to data from previous years to help forecast when control efforts will need to be performed. Predicting the need for larger-scale adulticiding will provide government agencies with the time needed to make decisions related to adulticide use.

Additionally, improving communication with people performing irrigation throughout the control area may help to improve control efforts.

Finally, there *may* be service gaps in border areas between where a contracted company and a governmental agency are performing mosquito control. If these gaps were filled, it *may* help provide improved mosquito control for the state. Generally, however, communication is very good between all agencies and mosquito control efforts are well organized.

What were your community's concerns? Many residents living in the areas where adulticiding was performed were concerned about the use of chemical pesticides. It was essential to communicate with the community that mosquito control is simply not the haphazard spraying of different chemicals, but instead an actual science. Once additional education was provided about the toxicity levels of the products, people were generally supportive of mosquito control efforts.

Occasionally, people verbalized concerns related to the adverse effects of adulticides on pets or wildlife, and education was provided that no such effects would result. Calls also were received from concerned horse owners, who were advised to vaccinate their horses. It has been shown that vaccination is worthwhile because significantly less WNV activity occurs in vaccinated horses compared to unvaccinated horses.

Sometimes, a landowner simply did not want adulticiding performed on his or her property, and this decision was respected.

Before WNV arrived, concerns were mostly nuisance-based. Currently, however, there are numerous additional concerns about mosquitoes beyond the nuisance factor. People are very concerned about WNV, wanting to know, "What can I do? What do I need to do? What can you do for me?"

How were these concerns addressed? Concerns were addressed either by phone or in person. Technicians who encountered land owners in the field would provide information as requested. Additionally, employees attended homeowner association meetings and city council meetings to provide education.

Spraying notifications were posted on the website of the contracted company in order for residents to access spraying information online. Additionally, a database was established that allowed residents living in control areas to request a phone call if spraying was going to be performed in their neighborhood or to request that the fogger in front of their house be turned off.

In general, the contacted company responded to nuisance complaints by going out to the area of concern, setting traps, looking at the data, and then determining if adulticiding was necessary. The arrival of WNV, however, modified this response to nuisance concerns in 2003. Spray routes occasionally were adjusted to prioritize areas with WNV-related concerns. For nuisance complaints, people were informed that public health emergencies were considered a priority over nuisance concerns.

4.2 Common Themes. Data were analyzed using a qualitative long-table approach (Krueger & Casey, 2000). Each of the individual research questions were written along the top of a poster board, and the transcribed response to each question was attached to the appropriate board. Once all the responses were in place, the boards were reviewed over the course of several days to extract common and/or significant themes for each of the research questions.

What species of mosquito and/or mosquito-borne diseases are the focus of control efforts in your jurisdiction? With regard to vector mosquitoes, the *Culex* complex was reported most often as the focus of control. With regard to nuisance mosquitoes, the species varied according to region. All participants were concerned about WNV, and five of the seven participants also were concerned about St. Louis encephalitis.

Please give me a very brief description of your program's overall approach to mosquito control. All seven participants considered their approaches to be integrated, combining multiple efforts to provide optimal mosquito control. Five of the seven IPM programs were quite extensive. All seven programs included public education to varying extents. Six of the seven participants discussed active surveillance programs carried out in their regions. The most common forms of surveillance utilized were testing mosquito pools for WNV (number of responses=5) and monitoring adult mosquito abundance (number of responses=5). Less frequent forms of surveillance included testing sentinel chickens for viral activity (number of responses=2); monitoring weather events and patterns, such as temperature and rainfall (number of responses=2); performing larval surveys to determine the species and concentration of regional mosquitoes (number of responses=2); and collecting and testing wild birds for viral activity (number of responses=2).

Larvaciding (treating mosquito breeding areas with biological or chemical agents to decrease larval abundance) was a component of all seven programs. Other forms of larval control utilized included mapping of breeding sites to determine areas where larvacide treatments and/or monitoring are indicated (number of responses=5); performing source reduction activities to reduce or eliminate breeding grounds for mosquitoes (number of responses=4); and using predator fish to consume mosquito larvae (number of responses=2). Finally, adulticiding was an optional component of all seven programs, although only five of the seven participants utilized adulticides in 2003.

Did your program use adulticides as part of its mosquito control efforts in 2003? Participants were selected for this study based on adulticide use in 2003: five programs were chosen that *did* use adulticides and two programs were chosen that *did not* use adulticides. Four programs *used* adulticides to control both vector and nuisance species. One program *used* adulticides to control mostly nuisance species in one small area of the district where other means of control were not feasible due to its remote location. One program *did not* use adulticides because no human cases of WNV had been identified in the county. Another program *did not* use adulticides because the threshold criteria for initiating adulticides (multiple human cases found in an area *or* human cases in conjunction with increased WNV activity in the mosquito population in the same area) had not been met.

For how long have adulticides been used in your program? Adulticides have been used for varying lengths of time, dating back as far as the 1940s and as recently as the 1990s.

Which adulticides are used in your program? Synthetic pyrethroids (Biomist-permethrin (number of responses=2), Scourge-resmethrin (number of responses=3), Anvil-sumithrin (number of responses=2)) were used most commonly for truck-mounted adulticide applicators performing ground control. The organophosphate naled (number of responses=2) was used most commonly for aerial control.

What were your reason(s) for selecting these particular adulticides as a suppression method? Synthetic pyrethroids were deemed desirable for numerous reasons, including effective mosquito knock-down rates, low cost, and relative safety. The organophosphate naled was desirable because of its rapid dissipation time in the environment and low application rate. Naled was also advantageous because mosquitoes had not developed resistance to this insecticide as they had to the organophosphate malathion.

Has an encephalopathy—particularly West Nile Virus—been found in your jurisdiction? WNV-related illnesses were identified in six of the seven participating districts. Specific encephalopathies were mentioned by three of the participants.

Before the arrival of the encephalopathy, when was the last time you used an adulticide in your jurisdiction. Among the six districts where WNV-related illnesses were identified, four had ongoing adulticide programs, one had not used adulticides in a residential area since the 1980s, and one had not used adulticides at all in recent years.

Did you use pre-defined threshold criteria for initiating or continuing use of adulticides during 2003? Pre-defined threshold criteria were used to initiate adulticiding by all seven participants. Thresholds varied widely; however, commonly mentioned criteria involved in the decision-making process included:

increased mosquito abundance (number of responses=4); human cases of mosquito-borne disease (number of responses=4); time of season (typically less adulticiding was performed during winter months and/or late in the mosquito season) (number of responses=3); nuisance complaints (number of responses=3); mosquito pools testing positive for disease (number of responses=3); presence of dead birds (number of responses=2); equine cases of mosquito-borne disease (number of responses=2); and weather factors, such as increased rainfall or temperatures (number of responses=2). In 2003, the identification of WNV-positive mosquito pools was the criteria used to initiate adulticiding in two participating districts.

What process was used to make decisions related to implementation of adulticide use? All seven participants mentioned that a combination of factors typically is utilized in making decisions about adulticiding. Threshold criteria are utilized as well as input from the community. Looking "at the whole picture" is essential, as opposed to using only one criterion.

Three of the participating programs were able to make decisions about adulticiding without requesting permission from any state or regional agency. Two of the districts were able to make decisions about adulticiding independent of a state or regional agency, except in special circumstances where a community-wide spray or spraying in state-designated lands is performed. Two of the districts required special permission from a local government official to perform adulticiding.

What methods did you use to measure the success of adulticide use? Six participants utilized methods to measure the success of adulticiding. Methods included pre- and post-spray traps to monitor mosquito abundance (number of responses=3), cage tests to monitor mosquito mortality (number of responses=2), and pre- and post-spray landing counts (number of responses=1).

Do you think that the application of adulticides was successful? Success of adulticiding in controlling targeted species varied. Among the three programs that measured success of adulticiding using pre- and post-spray trap counts, efficacy in reducing post-spray trap counts was reported as 20-30% , approximately 90%, and 95-99%. One of the two programs that measured success of adulticiding using cage tests reported efficacy in post-spray mosquito mortality as 10-20%. Two participants (FL, LA) provided numerical data to support the efficacy of mosquito control efforts in reducing disease transmission. Three other participants (TX, IL, NY) reported that adulticiding theoretically could be successful in controlling targeted species when performed *appropriately* and *consistently.* Ideal conditions for adulticiding are not always available, however.

What contributed to this success? For those districts that reported success with adulticiding, contributing factors included: performing adulticide treatments during peak hours of mosquito activity; using effective adulticiding agents; using surveillance to identify viral "hot-spots" where adulticide treatments were performed; and performing successive treatments (for example, three nights in a row) to contact effectively all mosquitoes.

What kept the effort from being more successful/what did not work? For those programs that felt adulticiding generally was not effective, contributing factors included: not performing treatments during the peak of transmission season; not always having "a good target to spray," physical barriers (for example, foliage) encountered by the mist; experiencing weather conditions that were not ideal for spraying; and inability to determine the actual effect(s) of adulticiding, as numerous factors (apart from adulticide treatments) can influence a trap count from day to day.

What were your community's concerns? Community concerns varied. Common themes, however, included the adverse human and/or ecological impacts of pesticides (number of responses=5) and the presence of WNV (number of responses=4). Less common concerns included a district *not* performing adulticiding and thus exposing its residents to a higher risk of disease transmission (number of responses=2), an individual's wanting to be pre-notified of spraying events (number of responses=2), mosquito nuisance/annoyance (number of responses=2), equine illness (number of responses=2), property damage (for example: car paint and plant life) (number of responses=1), and fear that an adulticiding aircraft was a terrorist aircraft (number of responses=1).

How were these concerns addressed? All seven participants reported performing public education as the primary means of addressing concerns. All agency employees provided education to community members as requested, either in person or over the phone. Additional approaches to providing education included: establishing community outreach programs (number of responses=4); using the media (number of responses=4); providing literature (number of responses=3); using the internet (number of responses=2); establishing a phone bank for people to contact with questions/concerns (number of responses=1); providing referrals to non-partisan information sources (number of responses=1); and working directly with anti-pesticide groups to foster good relationships (number of responses=1).

Additional means of addressing concerns included: providing a "no-spray" option for property owners (number of responses=3); providing a pre-notification of spraying (number of responses=3); and performing surveillance in response to nuisance complaints (number of responses=2).

Chapter 5-Conclusion

Ultimately, the results of this study did not demonstrate any distinct association between the use of adulticides as part of an IPM program and either increased or decreased transmission of WNV to humans. The New York agency that *did not* use adulticides in 2003 had no human cases of illness. The Texas agency that *did not* use adulticides in 2003, however, had numerous cases of WNV. Additionally, WNV-related illnesses were identified in each of the districts that *did* adulticide in 2003. As demonstrated by Spielman and Rossignol (1987), transmission of WNV to humans is dependent on many factors, including disease amplification cycle, temperature, rainfall, narrowness of host range, presence of suitable habitats for mosquito breeding, and the abundance of certain mosquito species. Transmission to humans may occur, therefore, despite effective mosquito control practices.

This study *has* demonstrated that an organized, integrated mosquito management program can be beneficial in decreasing mosquito annoyance and risk of disease transmission. The *contribution* of adulticiding to reducing mosquito-borne disease transmission as part of an integrated program, however, is unknown. As demonstrated by The World Health Organization's (WHO) Global Eradication of Malaria Program, controlling mosquito-borne disease with insecticides is extremely challenging. The well designed and coordinated malaria eradication program utilized DDT—the first modern insecticide—to control mosquito populations (Rossignol, 2002). The WHO had organizations in each country responsible for identifying human residences, assessing transmission parameters and parasite levels, applying insecticides, evaluating the campaign's efficiency, and delivering all necessary resources (Rossignol, 2002). Although the program almost eradicated malaria from Madagascar, it ultimately failed globally. Development of drug and insecticide resistance contributed to the unsuccessful campaign (Rossignol, 2002). Failure to evaluate the efficacy of the campaign using indices based on human morbidity and mortality was another limitation of the program (Rossignol, 2002).

Three recurring and/or themes were identified throughout the interviews. First, adulticiding *can be effective* in controlling targeted species if performed *appropriately* and *consistently.* Risk of disease transmission cannot be reduced to zero, however.

Second, adulticiding *is most effective* when utilized in conjunction with active surveillance, larval control, and/or education programs. Surveillance is required to identify mosquito species presence and abundance, and viral "hot-spots" where targeted adulticide treatments would be effective. Targeting adulticide treatments is vital because the random spraying of insecticides could increase the potential for adverse outcomes. Additionally, because numerous variables can impact adulticide treatments adversely, active larval control strategies are needed to adequately suppress mosquito populations. Finally, education is critical to allow community members to protect themselves against mosquito-borne diseases and to encourage them to participate actively in source reduction activities, thereby helping to further suppress mosquito populations.

Third, pre-defined threshold criteria are important tools for initiating adulticide use; however, these criteria are viewed as *guidelines* instead of rules. "Looking at the whole picture" when making decisions about adulticiding is essential, as opposed to rigidly following one specific criterion. Considering numerous factors may complicate the decision to use adulticides; however, will ensure the judicious use of pesticides.

In addition to these three recurring themes, this study also revealed that community concerns related to adulticiding varied widely. Although all seven mosquito control agencies described appropriate programs designed to address community concerns, one limitation arose. Three agencies offered a "no-spray" option for community residents, where the adulticide spray mechanism was disabled while passing a specific home. In residential neighborhoods where houses are close in proximity, however, this option would be relatively ineffective because the aerosol drift may carry adulticide into neighboring yards. As demonstrated in the literature by Lothrup et al (2002), failure to control adulticide drift can occur if wind conditions are not optimal. The "no spray" option, therefore, may have been an attempt to appease community residents rather than a consistently effective measure to protect people from adulticide exposure.

Techniques utilized to measure the success of adulticide applications generally relied on mosquito abundance, mortality, and/or landing rate counts. Although these techniques are viable and useful for measuring the numbers and/or activity of mosquitoes, they are not based on the epidemiology of WNV or of mosquitoes as disease vectors. Although some participants provided epidemiological data to support the efficacy of their integrated programs, the contribution of adulticiding to the success of these programs was not acknowledged. It is difficult, however, to measure the efficacy of adulticiding in reducing encephalitis transmission because so few cases of disease typically occur in a specific geographic location.

Notably, no "silver bullet" exists that easily can measure the efficacy of mosquito control efforts. An adaptive management approach (in which data is collected during mosquito-borne disease outbreaks and used "to incrementally improve management efficacy in successive years") generally is valuable (Ginsberg, 2001). Indeed, it may require many years of utilizing an adaptive management approach to determine if mosquito control efforts are effective in reducing disease transmission. The process of continually collecting and analyzing data from disease outbreaks, however, can assist in creating the most effective mosquito control program possible (Ginsberg, 2001).

Although *efficacy* in reducing encephalitis transmission remains unproven, research has demonstrated that adulticiding is more *cost-efficient* than caring for a person with mosquito-borne encephalitis, such as EEE. Villari, Spielman, Komar, McDowell, and Timperi (1995) estimated the economic burden of EEE among residents of eastern Massachusetts by enumerating any costs attributable to the disease. According to this study, insecticidal interventions designed to limit EEE transmission to humans cost an estimated $0.7 million to $1.4 million, depending on the extent of insecticidal treatments performed (Villari et al., 1995). The cost of *one person* suffering residual sequelae of EEE, however, was estimated as approximately $3 million dollars (Villari et al., 1995). Clearly, the financial burden of disease is greater than the cost of insecticidal treatments.

Interestingly, participants in the study did not directly discuss the concept of vectorial capacity, and most participants did not discriminate between pest management and vector control in their practices. The interviewee from Louisiana, however, was an exception. The Louisiana participant demonstrated an extensive knowledge of both pest and vector control practices, fluently discussing the differences in controlling for vector mosquitoes versus nuisance mosquitoes. This participant described an intimate knowledge of the mosquito species being controlled, and was the only participant to discuss an extensive monitoring program of mosquito control efforts. This Louisiana parish not only measured the success of adulticiding via pre- and post-treatment landing rates, but also monitored mosquito mortality via cage tests. This agency also routinely checked equipment and performed droplet tests to ensure the correct amount of adulticide was being dispensed. Finally, bioassay tests were utilized to monitor resistance in regional mosquito species. Finally, the Louisiana interviewee was able to provide statistical evidence, including incidence rates of disease, to support the efficacy of the program. Although refined control efforts resulted in decreased incidence of disease in this Louisiana parish in 2003, cases of WNV were identified nonetheless. These results indicate, as mentioned previously, that despite an extensive mosquito control program that includes the targeted use of adulticides, disease transmission still may occur.

Three possible sources of error warrant discussion. First, participants were not chosen at random; therefore, the results may not be generalizable to other vector districts. Second, mosquito control agencies that agreed to participate in this study may differ from those agencies that did not agree to participate in the study. Twelve agencies initially agreed to participate in this study; however, for varying reasons, five agencies later declined. One prospective interviewee declined participation in the study, citing "time constraints." Two additional prospective interviewees contacted the researcher to decline participation for unclear reasons. The final two prospective interviewees never responded to the follow-up e-mail reminding them of the study. Third, limitations inherent to performing interviews may have resulted in some information not being provided to the researcher. The interviews lasted anywhere from 20 to 45 minutes, and each participant was provided with the research questions in advance. Responses to specific questions, however, may have been incomplete. Due to time constraints, a participant inadvertently may have omitted a detail or may have decided not to share certain information.

The literature corresponds with participant feedback related to utilizing a comprehensive program for optimal mosquito control. The significance of having an extensive surveillance program was emphasized by DeBess (2002) and Goddard et al. (2002). Additionally, the utilization of larval control strategies in mosquito control was discussed by Walton et al. (1998) and Spielman & Rossignol, 1987). Finally, the critical role of education (frequently used to encourage source reduction and personal protection) was reviewed Espinoza-Gomez (2003), Roche (2002), and Gubler and Clark (1996).

Notably, education programs that reach the public effectively require substantial resources. The literature found that many Americans receive education about WNV and mosquito avoidance from the media (McCarthy et al., 1991). Additionally, both passive (receiving questions/concerns) and active (performing community outreach) educational programs are important components of mosquito control. Outreach programs should be extensive and creative, using diverse approaches to communicate with people in various settings (for example, homes, schools, and community meetings). Such educational programs, unfortunately, are extremely expensive to develop and maintain. As noted by Gubler & Clark (1996) and Roche (2002), however, these education programs are critical to the success of mosquito control. Adequate funding to support an extensive education program (in addition to the other components of an IPM program) should be provided to ensure communities are well-informed and actively engaged in mosquito control efforts.

The literature also supports participant feedback regarding the numerous factors can impact the efficacy of adulticiding, including: 1) choosing a suitable adulticide (Yap et al., 1997); 2) applying adulticides appropriately (Steinke & Yates, 1987; Lothrup et al., 2002; Tietze et al., 1994); 3) reducing components of vectorial capacity effectively (Spielman & Rossignol, 1987); 4) knowing which mosquito species to target for control (Goddard et al., 2002; Turell et al., 2001); 5) utilizing an intimate knowledge of complex mosquito behavior (Reiter et al., 1990; Lothrup et al., 2002; Reisen et al., 1997); 6) monitoring for mosquito resistance (Buss et al., 2002; Hemingway et al., 2002; Rose, 2001; Thompson, 2003); and 7) maintaining a comprehensive mosquito management program (Walton et al., 1998; Gubler & Clark, 1996; CDC—surveillance, 2003). Ultimately, the inability (or lack of knowledge needed) to control these factors may contribute to the varying success rates of adulticiding noted in this study.

The literature supports, however, that adulticiding *can be effective* when the previous factors that adversely effect adulticiding are considered carefully prior to an adulticide application. The following recommendations, therefore, can help *maximize* the contribution of adulticiding: 1) maintain an active surveillance program to target viral hot-spots; 2) monitor resistance of local mosquito populations to adulticides; 3) identify local mosquito species that are vector competent for WNV; 4) monitor factors that may influence vectorial capacity, such as environmental conditions and mosquito abundance; 5) develop and utilize an intimate knowledge of the feeding and resting behaviors of targeted mosquito species; 6) monitor adulticiding equipment to ensure it is working appropriately; 7) train all adulticide applicators to apply insecticides according to their labels and to use adulticiding equipment appropriately; 8) perform adulticiding only when a targeted area of increased mosquito and/or viral activity has been identified and environmental conditions are suitable; 9) perform consecutive treatments as needed to contact all targeted species; 10) utilize appropriate methods to measure the efficacy of adulticiding, including human case surveillance; and 11) garner community support and approval for adulticide efforts through effective communication strategies.

This study will provide new and/or useful information to the Multnomah County Health Department related to: 1) effective and ineffective practices in mosquito management as determined by varying agencies in the United States; 2) the importance of utilizing the concepts of vectorial capacity and vector competence to encourage the appropriate use of adulticides, thereby theoretically reducing the risk of encephalitis transmission to humans; and 3) the benefits, limitations, and risks of adulticide use as part of a mosquito management program.

Further research is needed, however, to: 1) assess the ecological and human impacts of adulticides using the dose and exposure rates realistic to an adulticide program; 2) gain an understanding of the human and ecological impacts of aggregate and cumulative exposures to pesticides, especially for special populations, such as children; and 3) determine the efficacy of adulticiding in interrupting or reducing the enzootic amplification of arboviruses, as well as the transmission of WNV to humans.

Bibliography

Ames, R.G. (2002). Pesticide impacts on communities and schools. *International Journal of Toxicology* 21, 397-402.

Ames, R.G., Narveson, R.S., Mengle, D.C., & Womeldorf, D. (1988). Cholinesterase depression in California municipal and mosquito abatement district pesticide applicators. *Journal of the American Mosquito Control Association* 4(4), 539-541.

Barker, C.M., Reisen, W.K., & Kramer, V.L. (2003). California state mosquito -borne virus surveillance and response plan: a retrospective evaluation using conditional simulations. *American Journal of Tropical Medicine* 68(5), 508-518.

Brattsten, L.B. & Sutherland, D.J. (2003). Insecticides recommended for mosquito control for New Jersey in 2003. The Rutgers Entomology, NJMCA, New Jersey Mosquito Homepage. Retrieved 2/25/04 from http://www-rci.rutgers.edu/~insects/bmpmcnj.htm#adu.

Bren, L. (2003). West Nile Virus: reducing the risk. *FDA Consumer* 37(1), 20 -27.

Buss, D.A., McCaffery, A.R., & Callaghan, A. (2002). Evidence for p-glycoprotein modification of insecticide toxicity in mosquitoes of the *Culex pipiens* complex. *Medical and Veterinary Entomology* 16, 218-222.

California Vector-Borne Disease Surveillance System (CVDS) (2004). Retrieved 3/22/04 from http://vector.ucdavis.edu/.

Canadian Coalition for Health and Environment (CCHE) (2002). West Nile Virus and mosquito control practices: survey of mosquito control practices and less toxic alternatives. Retrieved 2/2/04 from http://www.cche-info.com/pdf/cche--survey_of_mosquito_control_practices.pdf.

Center for Disease Control (CDC) (2003). Surveillance for acute insecticide-related illness associated with mosquito-control efforts—nine states, 1999-2002. Morbidity and mortality weekly report 52(27). Retrieved 12/16/03 from http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5227a1.htm.

Center for Disease Control (CDC) (2003). West Nile Virus-entomology.

Retrieved 2/5/04 from http://www.cdc.gov/ncidod/dvbid/westnile/mosquitoSpecies.htm.

Center for Disease Control (CDC) (2004). Statistics, surveillance, and control: West Nile Virus. Retrieved 2/13/04 from http://www.cdc.gov/ncidod/dvbid/westnile/surv&controlCaseCount03_detailed.htm.

DeBess, E.E. (2002). Oregon Department of Human Services. State of Oregon mosquito-borne disease response plan.

Dohm, D.J., O'Guinn, M.L., & Turell, M.J. (2002). Effect of environmental temperature on the ability of *Culex pipiens* (Diptera: Culicidae) to transmit West Nile Virus. *Journal of Medical Entomology* 39(1), 221-225.

Dohm, D.J., Sardelis, M.R., & Turell, M.J. (2002). Experimental vertical transmission of West Nile Virus by *Culex pipiens* (Diptera: Culicidae). *Journal of Medical Entomology* 39(4), 640-644.

Dohm, D.J. & Turell, M.J. (2001). Effect of incubation at overwintering temperatures on the replication of West Nile Virus in New York *Culex pipiens* (Diptera: Culicidae). *Journal of Medical Entomology* 38(3), 462-464.

Eliason, D.A., Campos, E.G., Moore, C.G., & Reiter, P. (1990). Apparent influence of bloodmeal digestion on the efficacy of ground applied ULV aerosols for the control of urban *Culex* mosquitoes II. Laboratory evidence. *Journal of the American Mosquito Control Association* 6(3), 371-375.

Enserick, M. (2002). West Nile's surprisingly swift continental sweep. *Science* 297(5589), 1988-1989.

Espinoza-Gomez, F., Hernandez-Suarez, C.M., & Coll-Cardenas, R. (2002). Educational campaign versus malathion spraying for the control of *Aedes aegypti* in Colima, Mexico. *Journal of Epidemiological Community Health* 56, 148-52.

Environmental Protection Agency (2002). Synthetic pyrethroids for mosquito control. Retrieved 12/16/2003 from www.epa.gov/pesticides/factsheets/pyrethroids4mosquitos.htm

Environmental Protection Agency (2002). Malathion for mosquito control.

Retrieved 12/16/2003 from http://www.epa.gov/pesticides/factsheets/malathion4mosquitos.htm

Florida Department of Agriculture and Consumer Services (FDACS) (2003). Mosquito-borne diseases and prevention. Retrieved 3/22/04 from http://www.flaes.org/westnile2001/WestNile.htm#Role%20of%20the%20Florida.

Florida Department of Environmental Protection (FDEP) (1998). Biological Assessment of five lakes in response to application of malathion for the control of the Mediterranean fruitfly (*Ceratilis capaitata*). *FDEP surface water monitoring section.* Retrieved 3/3/04 from http://216.239.57.104/search?q=cache:RuyyCx0RASYJ:www.dep.state.fl.us/water/bioassess/docs/biorepts/otherepts/umatmedf.pdf+biological+assessment+five+lakes+umatilla+&hl=en&start=1&ie=UTF-8.

Florida Mosquito Control Organization (FMCO) (2004). Retrieved 3/22/04 from http://www.floridamosquito.org/.

Fradin, M.S., & Day, J.F. (2002). Comparative efficacy of insect repellents against mosquito bites. *The New England Journal of Medicine* 347(1), 13-18.

Generic Environmental Impact Statement (GEIS) (2001). Appendix 3.DIII: Empirical studies of adulticides. Comprehensive Mosquito-Borne Disease Surveillance and Control Plan 3.DIII-1-3.DIII-15. Retrieved 4/4/04 from www.westchestergov.com/.../stingEIS/DGEISfiles/AppendixFiles/Appendix%203.DIIIempiricalstudies.pdf

Ginsberg, H.S. (2001). Integrated pest management and allocation of control efforts for vector-borne diseases. *Journal of Vector Ecology* 26(1), 32-38.

Goddard, J. (2002). Mosquito vector competence and West Nile Virus transmission. *Infectious Medicine* 19(2), 542-543.

Goddard, L.B., Roth, A.E., Reisen, W.K., & Scott, T.W. (2002). Vector competence of California mosquitoes for West Nile Virus. *Emerging Infectious Disease* 8(12), 1385-1391.

Gubler, D.J. & Clark, G.G. (1996). Community involvement in the control of *Aedes aegypti*. *Acta Tropica* 61, 169-179.

Guptill, S.C., Julian, K.G., Campbell, G.L., Price, S.D., & Marfin, A.A. (2003). Early season avian deaths from West Nile Virus as warnings of human infection. *Emerging Infectious Disease* 9(4), 483-484.

Hadnagy, W., Leng, G., Sugiri, D., Ranft, U., & Idel, H. (2003). Pyrethroids used indoors—immune status of humans exposed to pyrethroids following a pest-control operation. *International Journal of Hygiene and Environmental Health* 206, 93-102.

Harvard School of Public Health (HSPH) (2003). Many Americans in high-mosquito areas think their family likely to get West Nile Virus in the next month. *HSPS Press Releases*, January 13. Retrieved 12/20/04 from http://www.hsph.harvard.edu/press/releases/press01132003.html

Harvard School of Public Health (HSPH) (2003). Four in ten Americans in high -mosquito areas are not yet taking precautions against West Nile/mosquito bites. *HSPS Press Releases*, July 31. Retrieved 12/30/04 from http://www.hsph.harvard.edu/press/releases/press07312003.html

Hemingway, J., Field, L., & Vontas, J. (2002). An overview of insecticide resistance. *Science* 298(5591), 96-97.

Hester, P.G., Shaffer, K.R., Tietze, N.S., Zhong, H., & Griggs, N.L. (2001). Efficacy of ground-applied ultra-low-volume malathion on honey bee survival and productivity in open and forest areas. *Journal of the American Mosquito Control Association* 17(1), 2-7.

Howard, J.J. & Oliver, J. (1997). Impact of naled (Dibron 14) on the mosquito vectors of eastern equine encephalitis virus. *Journal of the American Mosquito Control Association* 13(4), 315-325.

Howe, F.P., Knight, R.L., McEwan, L.C., & George, T.L. (1996). Direct and indirect effects of insecticide applications on growth and survival of nestling passerines. *Ecological Applications* 6(4), 1314-1324.

Idaho Department of Health and Welfare (IDHW). West Nile Virus transmission cycle. Retrieved 2/16/04 from http://www2.state.id.us/dhw/cdp/westnile/transmission_cycle.htm

Illinois Department of Agriculture (2004) Commercial pesticide training and testing. Retrieved 3/22/04 from http://www.agr.state.il.us/Environment/Pesticide/training/commappl.html.

Illinois Department of Public Health (IDPH) (2004). West Nile Virus transmission cycle. Retrieved 2/16/04 from http://www.idph.state.il.us/envhealth/wnvtransmission.htm.

Illinois Dept of Public Health (IDPH-WNV) (2004). West Nile Virus. Retrieved 3/22/04 from http://www.idph.state.il.us/envhealth/wnv.htm.

Integrated Pest Management Institute (2002). What is IPM? Retrieved 1/5/2004 from http://www.ipminstitute.org/schoolipmweek.htm.

Jensen, T., Lawler, S.P., & Dritz, D.A. (1999). Effects of ultra-low volume pyrethrin, malathion, and permethrin on non-target invertebrates, sentinel mosquitoes, and mosquitofish in seasonally impounded wetlands. *Journal of the American Mosquito Association* 15(3), 330-338.

John, K.H., Stoll, J.R., & Olson, J.K. (1987). The public's view of mosquito problems in an organized control district. *Journal of the American Mosquito Control Association* 3(1), 1-7.

Knepper, R.G., Walker, E.D., Wagner, S.A., Kamrin, M.A., & Zabik, M.J. (1996). Deposition of malathion and permethrin on sod grass following single, ultra-low volume applications in a suburban neighborhood in Michigan. *Journal of the American Mosquito Control Association* 12(1), 45-51.

Krueger, R.A. and Casey, M.A. (2000). Focus groups: a practical guide for applied research (3rd ed). Thousand Oaks, California: Sage Publications.

Lopez, W. & Miller, J.R. (2002). The legal context of mosquito control for West Nile Virus in New York City. *The Journal of Law, Medicine, & Ethics* 3(30), 135-138.

Lothrup, H.D., Lothrup, B., & Reisen, W.K. (2002). Nocturnal microhabitat Distribution of adult *Culex tarsalis* (Diptera: Culicidae) impacts control effectiveness. *Journal of Medical Entomology* 39(4), 574-582.

Louisiana Mosquito Control Agency (LMCA) (2004). Retrieved 3/22/04 from http://www.lmca.us/.

McCarthy, T.A., Hadler, J.L., Julian, K., Walsh, S.J., Biggerstaff, B.J., Hinten, S.R., Baisley, C.B., Iton, A., Brennon, T., Nelson, R.S., Achambault, G., Marfin, A.A., & Peterson, L.R. (2001). West Nile Virus serosurvey and assessment of personal protection efforts in an area with intense epizootic activity: Connecticut, 2000. *Annals of the New York Academy of Sciences* 951, 307-16

McCarroll, L., Paton, M.G., Karunaratne, S.H., Jayasuryia, K.S., & Hemingway, J. (2000). Insecticides and mosquito-borne disease. *Nature* 407, 961-962.

McConnell, N. (2003, December). Summary of Multnomah County Mosquito Species. Paper presented at meeting with Multnomah County Vector and Nuisance Control, Portland, OR.

Montague, B., Birchfield, N., & Mahler, R. (2000). EFED RED chapter for malathion. Retrieved 3/3/04 from www.epa.gov/pesticides/op/malathion/efed_cover.pdf

Morris, C.D. & Clanton, K.B. (1998). Quantification of a nuisance mosquito problem in Florida. *Journal of the American Mosquito Control Association* 4(3), 377-379.

Mosquito and Vector Control Association of California (MVCAC) (2004). Retrieved 3/22/04 from http://www.mvcac.org/.

Mount, G.A., Biery, T.L., & Haile, D.G. (1996). A review of ultra-low volume aerial sprays of insecticide for mosquito control. Journal *of the American Mosquito Control Association* 12(4), 601-618.

Murray, A. (1985). Acute and residual toxicity of a new pyrethroid insecticide, WL85871, to honey-bees. *Bulletin of Environmental Contamination and Toxicology* 34, 560-564.

National Pesticide Information Center (NPIC) (1998). Fact Sheet: Pyrethrins and Pyrethroids. Retrieved 3/18/04 from http://www.npic.orst.edu/factsheets/pyrethrins.pdf.

National Pesticide Information Center (NPIC) (2000). Fact Sheet: Inert or "other" ingredients. Retrieved 3/18/04 from http://www.npic.orst.edu/factsheets/inerts.pdf.

National Pesticide Information Center (NPIC) (2001). Fact Sheet: Malathion. Retrieved 3/18/04 from http://www.npic.orst.edu/factsheets/malagen.pdf.

Nosal, B. & Pellizzari, R. (2003). West Nile Virus. *Canadian Medical*

Association Journal 168(11), 1443-1444.

Pasqual, J.A. (1994). No effects of a forest spraying of malathion on breeding blue tits (*Parus Caeruleus*). *Environmental Toxicology and Chemistry* 13(7), 1127-1131.

Read, N.R., Rooker, J.R., & Gathman, J.P. (1994). Public perception of mosquito annoyance measured by a survey and simultaneous mosquito sampling. *Journal of the American Mosquito Control Association* 10(1), 79-87.

Reisen, W.K., Lothrup, H.D., & Meyer, R.P. (1997). Time of host-seeking by *Culex tarsalis* (Diptera: Culicidae) in California. *Journal of Medical Entomology* 34(4), 431-437.

Reiter, P. (2001) Climate change and mosquito-borne disease. *Environmental Health Perspectives* 109(1), 141-160.

Reiter, P., Eliason, D.A., Francy, D.B., Moore, C.G., & Campos, E.G. (1990). Apparent influence of bloodmeal digestion on the efficacy of ground applied ULV aerosols for the control of urban *Culex* mosquitoes I. Field evidence. *Journal of the American Mosquito Control Association* 6(3), 366-370.

Roche, J.P. (2002). Print media coverage of risk-risk tradeoffs associated with West Nile encephalitis and pesticide spraying. *Journal of Urban Health* 79(4), 482-490.

Rose, R.I. (2001). Pesticides and public health: integrated methods of mosquito management. *Emerging Infectious Disease* 7(1), 17-23.

Rossignol, P.A. (2002). Global program to eradicate malaria. Unpublished manuscript, Oregon State university.

Sachs, J.S. (2003/2004). Poisoning the imperiled. *National Wildlife* 42(1), 22-30.

Sampathkumar, P. (2003). West Nile Virus: epidemiology, clinical presentation, diagnosis and prevention. *Mayo Clin. Proc.* 78, 1137-1144.

Shapiro, H. & Micucci, S. (2003). Pesticide use for West Nile Virus. *Canadian Medical Association Journal* 168(11), 1427-1430.

Shires, S.W. (1985). A step-wise evaluation of the effects of a new pyrethroids insecticide WL-85871 on honey-bees. *Pesticide Science* 6, 205.

Solomon, T, Ooi, M.H., Beasley, D.W., & Mallewa, M. (2003). *British Medical Journal* 326, 865-869.

Smith, T.M. & Stratton, G.W. (1986). Effects of synthetic pyrethroid insecticides on nontarget organisms. *Residue Reviews* 97, 93-120.

Spielman, A. & Rossignol, P.A. (1987). Chapter 20: Insect Vectors. Tropical and Geographical Medicine. New York: McGraw-Hill.

Steinke, W.E. & Yates, W.E. (1987). Modeling the behavior of a ULV adulticide application. *Proceedings and papers of the annual conference of the California Mosquito and Vector Control Association* 55, 67-76.

Sugg, W.C. & Wilson, M.L. (2001) Overkill: why pesticide spraying for West Nile Virus may cause more harm than good. Retrieved 1/21/04 from http://www.meepi.org/wnv/overkillma.htm.

Texas Department of Health (TDH) (2003). Texas West Nile Virus public health response guide. Retrieved 3/22/04 from http://www.tdh.state.tx.us/zoonosis/diseases/arboviral/westnile/information/wnResponse.pdf.

Thompson, M.A. (2003). West Nile Virus and insecticide resistance. *Mayo Clin. Proc.*78, 1579.

Tietze, N.S., Hester, P.G., & Shaffer, K.R. (1994). Mass recovery of malathion in simulated open field adulticide tests. *Archives of Environmental Contamination and Toxicology* 26, 473-477.

Tietze, N.S., Hester, P.G., Shaffer, K.R., & Wakefield, F.T. (1996). Peridomestic deposition of ultra-low volume malathion applied as a mosquito adulticide. *Bulletin of Environmental Contamination and Toxicology* 56, 210-218.

Tietze, N.S., Hester, P.G., & Shaffer, K.R. (1995). Acute effects of Permanone 31-66 (Permethrin-Piperonyl Butoxide) on nontarget minnows and grass shrimp. *Journal of the American Mosquito Control Association* 11(4) 476-479.

Turell, M.J., O'Guinn, M.L., Dohm, D.J., & Jones, J.W. (2001). Vector competence of North American mosquitoes (Diptera: Culicidae) for West Nile Virus. Journal of Medical Entomology 38(2), 131-134.

Villari P, Spielman A, Komar N, McDowell M, Timperi RJ. (1995). The economic burden imposed by a residual case of eastern encephalitis. *American Journal of Tropical Medicine and Hygiene* 52(1), 8-13.

Walton, W.E., Workman, P.D., Randall, L.A., Jiannino, J.A., and Offill, Y.A. (1998). Effectiveness of control measures against mosquitoes at a constructed wetland in southern California. *Journal of Vector Ecology* 23(2), 149-160.

Weill, M. Lutfalla, G., Mogensen, K., Chandre, F., Berthomieu, A., Berticat, C., Pasteur, N., Philips, A., Fort, P., & Raymond, M. (2003). Insecticide resistance in mosquito vectors. *Nature* 423, 137-138.

Wilkes, M.F. (2000). Pyrethroid-induced paresthesias—a central or local toxic effect? *Clinical Toxicology* 38(2), 103-105.

Yap, H.H., Chong, A.S.C., Adanan, C.R, Chong, N.L., Bohaizat, B., Malik, Y.A., & Lim, S.Y. (1997). Performance of ULV formulations (Pesguard 102/Vectobac 12AS) against three mosquito species. *Journal of the American Mosquito Control Association* 13(4), 384-388.

Appendix A
Fact Sheet: Pyrethrins and Pyrethroids

Retrieved 3/18/04 from http://www.npic.orst.edu/factsheets/pyrethrins.pdf

Updates occur to NPIC fact sheets from time to time and printed versions may differ from on-line versions in future dates.

NPTN fact sheets are designed to answer questions that are commonly asked by the general public about pesticides that are regulated by the U.S. Environmental Protection Agency (US EPA). This document is intended to be educational in nature and helpful to consumers for making decisions about pesticide use.

National
Pesticide
Telecommunications
Network

Pyrethrins & Pyrethroids

The Pesticide Label: Labels provide directions for the proper use of a pesticide product. *Be sure to read the entire label before using any product.* A signal word on each product label indicates the product's short-term toxicity.

CAUTION- low toxicity **WARNING- moderate toxicity** **DANGER- high toxicity**

What are pyrethrins?

- Pyrethrins are insecticides that are derived from the extract of chrysanthemum flowers (pyrethrum) (1).
- The plant extract, called pyrethrum contains pyrethrin I and pyrethrin II collectively, called pyrethrins.
- Pyrethrins are widely used for control of various insect pests.

What are pyrethroids?

- Pyrethroids are synthetic (human-made) forms of pyrethrins. There are two types that differ in chemical structure and symptoms of exposure.
- Type I pyrethroids include allethrin, tetramethrin, resmethrin, d-phenothrin, bioresmethrin, and permethrin (1, 2).
- Some examples of type II pyrethroids are cypermethrin, cyfluthrin, deltamethrin, cyphenothrin, fenvalerate, and fluvalinate (1, 2).
- Both type I and II pyrethroids inhibit the nervous system of insects. This occurs at the sodium ion channels in the nerve cell membrane. Some type II pyrethroids also affect the action of a neurotransmitter called GABA (3).

How do pyrethrins (and pyrethroids) work?

- Nerve cell membranes have a specific electrical charge. Altering the amount of ions (charged atoms) passing through ion channels causes the membrane to depolarize which, in turn, causes a neurotransmitter to be released. Neurotransmitters help nerve cells communicate. Electrical messages sent between nerve cells allow them to generate a response, like a movement in an animal or insect.
- Pyrethrins affect the nervous system of insects by causing multiple action potentials in the nerve cells by delaying the closing of an ion channel (3).
- Pyrethrins and pyrethroids act as contact poisons, affecting the insect's nervous system (1, 4).
- Even though pyrethrins and pyrethroids are nerve poisons, they are not cholinesterase inhibitors like organophosphate or carbamate insecticides.
- Pesticide products containing pyrethrins usually contain a synergist (such as piperonyl butoxide). Synergists work by restricting an enzyme that insects use to detoxify the pyrethrins. A synergist allows the insecticide to be more effective (4).

There are many different types of pyrethroids, but the remainder of this fact sheet will deal with pyrethrins. Information on specific pyrethroids is available in other fact sheets.

What are some types of products that contain pyrethrins?

- indoor bugbombs or foggers
- human head-lice treatments
- pet flea sprays
- Dragon
- Drione
- Pyrenone
- Pyrocide

How toxic are pyrethrins?

Animals
- Pyrethrins are one of the least poisonous insecticides to mammals (2).
- Rats fed high doses (1,000 milligrams per kilogram of body weight or mg/kg) of pyrethrins showed liver damage (5).
- Rats exposed to pyrethrins exhibited difficulty or rapid breathing, incoordination, sprawling of limbs, tremors, aggression, sensitivity to external stimuli, twitching, and exhaustion (6). See box on **laboratory testing.**

Humans
- Inhaling pyrethrins can cause coughing, wheezing, shortness of breath, runny or stuffy nose, chest pain, or difficulty breathing (7).
- Skin contact can cause a rash, itching, or blisters (7).

> **Laboratory Testing**: Before pesticides are registered by the U.S. EPA, they must undergo laboratory testing for short-term and long-term health effects. In these tests, laboratory animals are purposely fed a pesticide at high doses to cause toxic effects. These tests help scientists judge how these chemicals might affect humans, domestic animals, and wildlife in cases of overexposure. When pesticide products are used according to the label directions, toxic effects are not likely to occur because the amount of pesticide that people and animals may be exposed to is low compared to the doses fed to laboratory animals.

> Effects of pyrethrins on human health and the environment depend on how much pyrethrins are present and the length and frequency of exposure. Effects also depend on the health of a person and/or certain environmental factors.

Do pyrethrins cause sensitization?

Animals
- The crude pyrethrum (initial plant extract) contains about 30 to 35 percent pyrethrins and about 50 percent impurities (2, 5).
- Various extracts from pyrethrum flowers have caused allergic contact dermatitis in sensitized and unsensitized guinea pigs (8). The commercially refined extract, which is present in insecticides today, did not produce any allergic reactions in guinea pigs (8, 9).
- Sensitization sometimes occurs in some individuals after a single exposure which causes either an asthmatic condition or a skin rash or inflammation. After the initial exposure to the sensitizing agent, the sensitized individual responds to a dose smaller than the initial dose.

Humans
- In one study, a person with a history of allergic contact dermatitis experimentally exposed to crude pyrethrum developed contact dermatitis, although this may have been caused by impurities in the extract (10).

Do pyrethrins break down and leave the body?

Animals
- Pyrethrins are low in toxicity to mammals because they are quickly broken down into inactive forms and pass from the body in the urine and feces (2, 5).

Humans
- Pyrethrum (the plant extract) may be absorbed by the digestive tract and the lungs. However, it is poorly absorbed through the skin (5).
- Based on animal studies, any amount of pyrethrins absorbed by humans would be expected to be rapidly excreted. Therefore, it is unlikely that pyrethrins

would accumulate in humans.

Are pyrethrins likely to cause cancer?

Animals

- In one study, rats were fed moderate to very high doses (100, 1000, or 3000 mg/kg) of pyrethrum (the plant extract) for 104 weeks. There was an increase in the non-cancerous (benign) thyroid tumors in females exposed to all doses and in males exposed to high to very high doses (11).
- In the same study, some females fed high doses (3000 mg/kg) of pyrethrum developed ovarian and benign liver tumors and males exposed to high doses (3000 mg/kg) developed benign parathyroid tumors and benign skin lesions.
- In another study, rats were fed low doses (up to 10 mg/kg) of pyrethrins, flavoring agents, and other pesticides showed no increase in tumors (6).

Humans

- Scientists have no data from work-related, accidental poisonings, or epidemiological studies that indicate whether or not pyrethrins are likely to cause cancer in humans.
- Initially, the Health Effects Division Carcinogenicity Peer Review Committee (CPRC) at the US EPA recently reviewed the carcinogenicity data of pyrethrins in animals and decided that they showed carcinogenicity. However, the CPRC could not classify pyrethrins into a carcinogenicity group until some of the tissue specimens from rats and mice were re-read. Subsequently, the CPRC will perform a second review of the carcinogenicity of pyrethrins (11).

Cancer: The U.S. EPA has strict guidelines that require testing of pesticides for their potential to cause cancer. These studies involve feeding laboratory animals large <u>daily</u> doses of the pesticide for up to 2 years. These animals are compared with a group of animals that did not receive the chemical. Animal studies help show whether a chemical is a potential human carcinogen. If a pesticide does not cause cancer in animal tests, then the EPA considers it unlikely the pesticide will cause cancer in humans.

Do pyrethrins cause reproductive problems or birth defects?

Animals

- Rabbits fed moderate doses (up to 90 mg/kg) of pyrethrins during a sensitive period of pregnancy had normal litters (5).
- Rats fed very high doses (5000 mg/kg) of pyrethrins for three weeks before their first mating produced low birth weight pups (5).
- There were no birth defects in pups of rabbits exposed to pyrethrins (12).

Humans

- There are no epidemiological, work-related or accidental exposure data on the potential of pyrethrins to cause reproductive problems or birth defects.

What happens to pyrethrins in the environment?

Soil

- Pyrethrins have a soil half-life of 12 days (13). They have an extremely low pesticide movement rating because they bind tightly to the soil (13). See box on **half-life.**

Photodegredation

- Pyrethrins are unstable in light or air (2). Pyrethrins are rapidly degraded in sunlight at the soil surface and in water.

Half-life is the time required for half of the compound to degrade.

1 half-life	=	**50% degraded**
2 half-lives	=	**75% degraded**
3 half-lives	=	**88% degraded**
4 half-lives	=	**94% degraded**
5 half-lives	=	**97% degraded**

Remember that the amount of chemical remaining after a half-life will always depend on the amount of the chemical originally applied.

What effects do pyrethrins have on wildlife?

- Pyrethrins are highly toxic to fish and tadpoles. They affect their skin touch receptors and balance organs (4).
- Pyrethrins are toxic to beneficial insect (such as honeybees) and many aquatic invertebrates (4).
- Pyrethrins are low in toxicity to humans, other mammals, and birds (4).

References

1. Klaassen, C. D., Amdur, M. O., & Doull, J. (Eds.). (1996). *Casarett & Doull's Toxicology. The Basic Science of Poisons* (5th ed.). Toronto: McGraw-Hill Companies, Inc.
2. Ray, D. E. (1991). Pesticides derived from plants and other organisms. In W. J. Hayes, Jr. & E. R. Laws (Eds.), *Handbook of Pesticide Toxicology. Vol. 2.* (pp.585-593). Toronto: Academic Press.
3. Costa, L. G. (1997). Basic Toxicology of Pesticides. In M. C. Keifer, M. D., M. P. H. (Ed.), *Human Health Effects of Pesticides. Occupational Medicine. State of the Art Reviews.* (Vol. 12 No. 2). (pp. 251-268). Philadelphia: Hanley & Belfus, Inc.
4. Tomlin, C. (Ed.). (1994). *A World Compendium. The Pesticide Manual. Incorporating the agrochemicals handbook.* (10th ed.). Bungay, Suffolk, U.K.: Crop Protection Publications.
5. Hayes, W. J. (1982). *Pesticides Studied in Man.* Baltimore: Williams & Wilkins.
6. Leahey, J. P. (Ed.). (1985). The pyrethroid insecticides. Philadelphia: Taylor & Francis Ltd.
7. Sittig, M. (1991). *Handbook of Toxic and Hazardous Chemicals and Carcinogens.* (3rd ed.). (Vol. 2). New Jersey: Noyes Publications.
8. Rickett, F. E., Tyszkiewicz, K., and Brown, N. C. (1972). *Pyrethrum dermatitis. I. The allergenic properties of various extracts of pyrethrum flowers.* Pestic. Sci. 3:57-66.
9. Rickett, F. E. and Tyszkiewicz, K. (1973). *Pyrethrum dermatitis. II. The allergenicity of pyrethrum oleoresin and its cross-reactions with saline extract of pyrethrum flowers.* Pestic. Sci. 4:801-810.
10. Mitchell, J. C., Dupuis, G. H. N. (1972). *Allergenic dermatitis from pyrethrum (Chrysanthemum spp.). The roles of pyrethrosin, a sesquiterpene lactone, and of pyrethrin II.* Br. J. Derm. 86:568-573.
11. United States Environmental Protection Agency (US EPA). Office of Prevention, Pesticides and Toxic Substances. *Carcinogenicity Peer Review of Pyrethrins.* February 22, 1995. Washington, DC.
12. Vettorazzi, G. (1979). *International Regulatory Aspects for Pesticide Chemicals. Toxicity Profiles.* (Vol.1). Boca Raton, Florida: CRC Press, Inc.
13. Wauchope, R. D., T. M. Butler, A. G. Hornsby, P. M. Augustijn-Beckers, & J. P. Burt. (1992). The SCS/ARS/CES pesticide properties database for environmental decision making. *[Online]. ftp://ftp.nrcs.usda.gov/centers/itc/applications/wqmodels/gleams/*

For more information, call or write:
NPTN, Oregon State University, 333 Weniger Hall, Corvallis, Oregon 97331-6502.
Phone: 1-800-858-7378
Fax: 1-541-737-0761
Email: nptn@ace.orst.edu
Internet: http://ace.orst.edu/info/nptn/ or http://ace.orst.edu/info/extoxnet/

Date reviewed: December 1998

Appendix B
Fact Sheet: Malathion

Retrieved 3/18/04 from http://www.npic.orst.edu/factsheets/malagen.pdf

Updates occur to NPIC fact sheets from time to time and printed versions may differ from on-line versions in future dates.

NPIC Technical Fact Sheets are designed to provide information that is technical in nature for individuals with a scientific background or familiarity with the regulation of pesticides by the U.S. Environmental Protection Agency (U.S. EPA). This document is intended to be helpful to professionals and to the general public for making decisions about pesticide use.

National
Pesticide
Information
Center

Malathion

(General Fact Sheet)
Please refer to the **Technical Fact Sheet** for more technical information.

The Pesticide Label: Labels provide directions for the proper use of a pesticide product. *Be sure to read the entire label before using any product.* A signal word on each product label indicates the product's potential hazard.

CAUTION - low toxicity **WARNING - moderate toxicity** **DANGER - high toxicity**

What is malathion?

- Malathion is an insecticide that was registered for use in the United States in 1956 (1).
- Malathion belongs to a class of insecticides known as organophosphates (OPs) (2).
- Malathion is a yellow to brown liquid with a skunk- or garlic-like odor. It dissolves slightly in water and does not readily evaporate into the air. It may damage metal and some forms of plastic and rubber (3).
- Malathion products are used to control a variety of insects outdoors and are sold in the form of dusts, liquids, aerosols, and wettable powders (4).
- Signal words for products containing malathion range from Caution to Danger (5). The signal word reflects the combined toxicity of malathion and other ingredients in each product. See the **Pesticide Label** box above.

How does malathion work?

- Malathion kills insects by disrupting the nervous system (4). It does this by inhibiting an enzyme called cholinesterase (4, 6, 7).
- Malathion affects the nervous systems of insects and humans. Insects are more susceptible to it than mammals (4).

What types of products contain malathion?

- Agricultural insecticides for food and non-food crops
- Home-use products for vegetable gardens, ornamental plants, and lawns
- Mosquito control insecticides
- Insecticides used in the Cotton Boll Weevil and Mediterranean Fruit Fly (Medfly) Eradication Programs

NOTE: Some head lice products contain malathion – these are regulated by the U.S. Food and Drug Administration (FDA) (4). This fact sheet **does not** address head lice products.

How toxic is malathion?

Animals

- Malathion is very low in toxicity when ingested by rats (4, 8). See boxes on **Laboratory Testing, Toxicity Category,** and **LD50/LC50.**
- Malathion is very low in toxicity when inhaled by rats (4, 8).
- Malathion is low in toxicity when applied to the skin of rats (4, 8).
- Impurities in malathion products can increase the toxicity of malathion to rats (6, 7). These impurities may result from manufacturing or storage (6). Malathion impurities may be toxic themselves or may increase the toxicity of malathion (9).
- In a skin irritation study, malathion caused slight skin irritation to rabbits. The EPA classifies malathion as very low in toxicity for skin effects (4).
- In studies with guinea pigs, malathion did not cause skin sensitivity (4).
- In a study with rabbits, malathion caused slight eye irritation (4). Malathion caused no eye effects in a study with rats (10). The U.S. EPA classifies malathion as low in toxicity for eye effects (4).
- Scientists exposed the skin of rabbits to malathion for three weeks and noted cholinesterase inhibition at the two highest doses tested. One rabbit died at the highest dose in the study (11).

Exposure: Effects of malathion on human health and the environment depend on how much malathion is present and the length and frequency of exposure. Effects also depend on the health of a person and/or certain environmental factors.

Laboratory Testing: Before pesticides are registered by the U.S. EPA, they must undergo laboratory testing for short-term (acute) and long-term (chronic) health effects. Laboratory animals are purposely fed high enough doses to cause toxic effects. These tests help scientists judge how these chemicals might affect humans, domestic animals, and wildlife in cases of overexposure. When pesticide products are used according to the label directions, toxic effects are not likely to occur because the amount of pesticide that people and pets may be exposed to is low compared to the doses fed to laboratory animals.

Toxicity Category (*Signal Word*) (12)

	High Toxicity (*Danger*)	Moderate Toxicity (*Warning*)	Low Toxicity (*Caution*)	Very Low Toxicity (*Caution*)
Oral LD50	Less than 50 mg/kg	50 - 500 mg/kg	500 - 5000 mg/kg	Greater than 5000 mg/kg
Dermal LD50	Less than 200 mg/kg	200 - 2000 mg/kg	2000 - 5000 mg/kg	Greater than 5000 mg/kg
Inhalation LC50	Less than 0.05 mg/l	0.05 - 0.5 mg/l	0.5 - 2 mg/l	Greater than 2 mg/l
Eye Effects	Corrosive	Irritation persisting for 7 days	Irritation reversible within 7 days	Minimal effects, gone within 24 hrs
Skin Effects	Corrosive	Severe irritation at 72 hours	Moderate irritation at 72 hours	Mild or slight irritation

LD50/LC50: A common measure of acute toxicity is the lethal dose (LD50) or lethal concentration (LC50) that causes death (resulting from a single or limited exposure) in 50 percent of the treated animals. LD50 is generally expressed as the dose in milligrams (mg) of chemical per kilogram (kg) of body weight. LC50 is often expressed as mg of chemical per volume (e.g., liter (L)) of medium (i.e., air or water) the organism is exposed to. Chemicals are considered highly toxic when the LD50/LC50 is small and practically non-toxic when the value is large. However, the LD50/LC50 does not reflect any effects from long-term exposure (i.e., cancer, birth defects, or reproductive toxicity) that may occur at levels below those that cause death.

- Male and female rats inhaling malathion for three months displayed cholinesterase inhibition at all doses tested. Researchers also noted respiratory system effects (11).

- Researchers fed dogs malathion for 1 year,and cholinesterase activity decreased at all doses for the animals. Researchers did not detect any signs of toxicity (8, 11).

Humans (See box on **Human Studies**)

- Volunteers ingested malathion for 47 days and displayed no significant cholinesterase activity effects. Volunteers eating malathion for 56 days had reduced cholinesterase activity three weeks after the dosing period in the study. This made the relationship of cholinesterase inhibition to malathion exposure uncertain (6).

- Volunteers who inhaled malathion products for 42 days showed no cholinesterase activity effects and no signs of poisoning (6).

- Volunteers exposed to malathion dust on their skin and clothes for 8 or more weeks complained of skin irritation and odor. Scientists noted cholinesterase inhibition at the highest dose but did not consider it significant (6).

Human Studies: Results from human studies are presented for information purposes only. The U.S. EPA presently does not use data from human studies in its risk assessments (EPA has asked the National Academy of Sciences to make "recommendations regarding the particular factors and criteria EPA should consider to determine the potential acceptability ...") of data from human studies. "... During the Academy's consideration of the issues and until a policy is in place, the Agency will not consider or rely on any such human studies in its regulatory decision making, whether previously or newly submitted. ..." – **Quotes from:** Environmental News R-246, U.S. EPA, December 14, 2001.

- Researchers conducted a study evaluating the health effects associated with people living in areas treated with malathion by ground and air applications. The applications, which occurred from April 1998 to September 1998, generated 230 reports of pesticide-related illness. Of these, 123 reports were listed as probable or possible cases. The most-commonly reported signs and symptoms were associated with the respiratory, gastrointestinal, and nervous systems (13).

- In a separate study, air applications of malathion from December 1989 to June 1990 generated 1,874 reports of pesticide-related illness. The majority of complaints (1,575), dealt with respiratory tract irritation, headaches, gastrointestinal tract symptoms, and fatigue. The other 299 complaints dealt with skin rashes (14).

- Researches associated a human outbreak of malathion poisoning in 1976 with product impurities (6). The U.S. EPA concludes that current impurities in malathion products do not pose a health concern (4).

- Signs and symptoms associated with malathion poisoning may include headaches, nausea, vomiting, dizziness, muscle weakness, sluggishness, and nervousness. In severe or life-threatening poisonings, breathing problems, diarrhea, tremors, confusion, seizures, and coma may occur. Signs relatively specific to organophosate poisoning include pinpoint pupils, eye tearing, increased sweating and salivation, and localized muscle contractions (15).

Does malathion break down and leave the body?

Animals

- Rats exposed to malathion excreted the majority of the chemical in the urine within the first day. Malathion did not accumulate in the exposed rats (4, 8).

Humans

- Volunteers absorbed small amounts of malathion applied to their skin. Maximum malathion excretion occurred within the first day (16).

Does malathion cause reproductive or birth defects?

Animals

- Two generations of rats that were fed malathion in their food exhibited no adverse effects on their fertility. The offspring had lower body weights at the two highest doses, while adult rats displayed lower body weights only at the highest dose (11).

- Pregnant rats fed malathion during pregnancy had offspring with no birth defects. Mother rats ate less and had lower weight gains at the highest dose tested (8, 11).

- Rabbits fed malathion during pregnancy had mothers with lower body weight gains and offspring with developmental effects at the two highest doses tested (8, 11).

Humans

- Data are not available from work-related exposures, accidental poisonings, or other human studies regarding the reproductive and developmental toxicity of malathion.

Does malathion cause cancer?

Animals

- Female rats fed malathion in their diet for 2 years had a higher number of liver tumors. Male rats did not. The U.S. EPA concluded that liver tumors in female rats only occurred at excessively high doses (11).

- Male and female mice fed malathion in their diet for 1.5 years had a higher number of liver tumors. The U.S. EPA concluded that liver tumors in the mice only occurred at excessively high doses (11).

- Researchers often test chemicals for their ability to change the genetic material of an organism as an indication of their potential to cause cancer. Evidence exists that malathion may change genetic material, but the U.S. EPA concludes that malathion is not a significant mutagenic hazard (4, 8, 17).

Humans

- The U.S. EPA classifies malathion as containing "suggestive evidence of carcinogenicity but not sufficient to assess human carcinogenic potential" (11). See box on **Cancer**.

- In a study of workers exposed to malathion, researchers did not detect an increased risk of genetic change. The small sample size in the study prevented definitive conclusions (18).

- Eight human studies concluded an increased risk for genetic changes with malathion exposure. Study interpretation is limited because researchers did not consider other contributing factors (17).

> **Cancer:** The U.S. EPA has strict guidelines that require testing of pesticides for their potential to cause cancer. These studies involve feeding laboratory animals large *daily* doses of the pesticide over most of the lifetime of the animal. Based on these tests, and any other available information, EPA gives the pesticide a rating for its potential to cause cancer in humans. For example, if a pesticide does not cause cancer in animal tests at large doses, then the EPA considers it unlikely the pesticide will cause cancer in humans. Cancer tests are not conducted on human subjects.

What happens to malathion in the environment?

- Malathion does not degrade readily by sunlight. It does break down in water under certain conditions (9).
- Malathion can move through soil, but it breaks down quickly. Malathion does not pose a great risk to ground water (9, 19).
- Malathion does not readily enter air from bodies of water (20)
- On plant surfaces, the time required for half of the malathion to disappear ranges from less than 1 day to about 1 week (9, 21). See box on **Half-life**.
- In the environment, microbes and water often degrade malathion into compounds of lower toxicity. However, malathion may be converted into more toxic substances under some conditions (9, 22).

Half-life is the time required for half of the compound to degrade.

1 half-life	=	**50% degraded**
2 half-lives	=	**75% degraded**
3 half-lives	=	**88% degraded**
4 half-lives	=	**94% degraded**
5 half-lives	=	**97% degraded**

Remember that the amount of chemical remaining after a half-life will always depend on the amount of the chemical originally applied.

What effects does malathion have on wildlife?

- Malathion is slightly to moderately toxic to various bird species (9).
- Malathion is considered moderate to very high in toxicity to fish and other water organisms (9).
- Malathion is not expected to build up in fish and other water organisms (20).
- Malathion is highly toxic to bees (9).

Date reviewed: February, 2001

For more information contact: NPIC
Oregon State University, 333 Weniger Hall, Corvallis, Oregon 97331-6502.
Phone: 1-800-858-7378 Fax: 1-541-737-0761 Email: npic@ace.orst.edu
NPIC at http://npic.orst.edu/ EXTOXNET at http://ace.orst.edu/info/extoxnet/

References

1. *Pesticide Fact Sheet Number 152: Malathion*; U.S. Environmental Protection Agency, Office of Pesticide Programs, U.S. Government Printing Office: Washington, DC, 1988.
2. Chamber, H. W. Organophosphorus Compounds: An Overview. In *Organophosphates: Chemistry, Fate, and Effects*; Chambers, J. E., Levi, P. E., Eds.; Academic: San Diego, CA, 1992; pp 3-17.
3. Malathion. In *Hazardous Substances Data Bank (HSDB)* [CD-ROM]; U.S. National Library of Medicine: Bethesda, MD, March 2000.
4. U.S. Environmental Protection Agency, Office of Pesticide Programs, Washington, DC. Malathion Preliminary Risk Assessments: Health Effects. http://www.epa.gov/pesticides/op/malathion.htm (accessed Nov 2000).
5. *Pest-Bank Pesticide Product Data* [CD-ROM]: Purdue Research Foundation: West Lafayette, IN, 2000.

6. Gallo, M. A.; Lawryk, N. J. Organic Phosphorus Pesticides. In *Handbook of Pesticide Toxicology;* Hayes, W. J., Laws, E. R., Eds.; Academic: San Diego, CA, 1991; Vol. 2, pp 917-1123.
7. World Health Organization. *Organophosphorus Insecticides: A General Introduction*, Environmental Health Criteria, 63, Geneva, Switzerland, 1986.
8. Marrs, T. C. Malathion. In *Pesticide residues in food, Joint FAO/WHO Meeting on Pesticide Residues, Evaluations 1997: Part II - Toxicological and Environmental*; International Programme on Chemical Safety, World Health Organization: Geneva, Switzerland, 1998; pp 189-219.
9. U.S. Environmental Protection Agency, Office of Pesticide Programs, Washington, DC. Malathion Preliminary Risk Assessments: Environmental Fate and Effects. http://www.epa.gov/pesticides/op/malathion.htm (accessed Nov 2000).
10. Boyes, W. K.; Hunter, E.; Gary, C.; Jensen, K.; Peiffer, R. L. Topical Exposure of the Eyes to the Organophosphorus Insecticide Malathion: Lack of Visual Effects. *J. Appl. Toxicol.* **1999**, *19*, 473-483.
11. U.S. Environmental Protection Agency, Office of Pesticide Programs, Washington, DC. Malathion Preliminary Risk Assessments: Toxicology Chapter. http://www.epa.gov/pesticides/op/malathion.htm (accessed Nov 2000).
12. U.S. Environmental Protection Agency, Office of Pesticide Programs, Washington, DC. Label Review Manual. http://www.epa.gov/oppfod01/labeling/lrm/chap-08.htm (accessed Nov 2000).
13. Shafey, O.; Sekereke, H. J.; Hughes, B. J.; Heber, S.; Hunter, R. G.; Brooks, R. G. Surveillance for Acute Pesticide-Related Illness During the Medfly Eradication Program-Florida. *MMWR* **1999,** *282*, 1015-1027.
14. Schanker, H. M.; Rachelefsky, G.; Siegel, S.; Katz, R.; Spector, S.; Rohr, A.; Rodriquiz, C.; Woloshin, K.; Papanek, P. J. Jr. Immediate and delayed type hypersensitivity to malathion. *Ann. Allergy* **1992,** *69*, 526-528.
15. U.S. Environmental Protection Agency, Office of Pesticide Programs, Washington, DC. Malathion Preliminary Risk Assessments: Review of Malathion Incident Reports. http://www.epa.gov/pesticides/op/malathion.htm (accessed Oct 2000).
16. Wester, R. C.; Maibach, H. I.; Bucks, D. A.; Guy, R. H. Malathion Percutaneous Absorption after Repeated Administration to Man. *Toxicol. Appl. Pharmocol.* **1983,** *68*, 116-119.
17. Flessel, P.; Quintana, P. J. E.; Hooper, K. Genetic Toxicity of Malathion: A Review. *Environ. Mol. Mutagen.* **1993,** *22*, 7-17.
18. Windham, G. C.; Titenko-Holland, N.; Osorio, A. M.; Gettner, S.; Reinisch, F.; Haas, R.; Smith, M. Genetic Monitoring of Malathion-Exposed Agricultural Workers. *Am. J. Ind. Med.* **1998,** *33*, 164-174.
19. Hornsby, A. G.; Wauchope, D. R.; Herner, A. E. *Pesticide Properties in the Environment*; Springer: New York, 1999; p 134.
20. Howard, P. H. *Handbook of Environmental Fate and Exposure Date for Organic Compounds*. Lewis: Chelsea, MI, 1991; pp 474-485.
21. Bradman, M. A.; Harnly, M. E.; Goldman, L. R.; Marty, M. A.; Dawson, S. V.; Dibartolomeis, M. J. Malathion and Malaoxon Environmental Levels Used for Exposure Assessment and Risk Characterization of Aerial Applications to Residential Areas of Southern California. *J. Expos. Anal. Environ. Epidemiol.* **1994,** *4*, 49-63.
22. Brown, M. A.; Petreas, M. X.; Okamoto, H. S.; Mischke, T. M.; Stephens, R. D. Monitoring of Malathion and Its Impurties and Environmental Transformation Products on Surfaces and in Air Following an Aerial Application. *Environ. Sci. Technol.* **1993,** *27*, 388-397.

Appendix C
Fact Sheet: Inert and "Other" Ingredients

Retrieved 3/18/04 from http://www.npic.orst.edu/factsheets/inerts.pdf

Updates occur to NPIC fact sheets from time to time and printed versions may differ from on-line versions in future dates.

NPTN fact sheets are designed to answer questions that are commonly asked by the general public about pesticides that are regulated by the U.S. Environmental Protection Agency (US EPA). This document is intended to be educational in nature and helpful to the public for making decisions about pesticides.

National **P**esticide **T**elecommunications **N**etwork

Inert or "Other" Ingredients

The Pesticide Label: Labels provide directions for the proper use of a pesticide product. *Be sure to read the entire label before using any product.* A signal word, on each product label, indicates the product's potential hazard.

CAUTION - low toxicity **WARNING - moderate toxicity** **DANGER - high toxicity**

What is an inert ingredient?

- An inert ingredient is a chemical in a pesticide product that does not have direct pesticidal activity against the target pest (*1*). See **Pesticide Products** box.
- Active ingredients and inert ingredients are combined to make a product formulation (*1*).
- Inert ingredients are also known as "other" ingredients (*2*).
- The total percentage of inert ingredient(s) is listed on each pesticide label.

Pesticide Products. A pesticide product is a commercially available mixture of chemicals used to kill, repel, or otherwise control one or more specific pest. The product consists of the active ingredient(s) and the inert ingredient(s). Active ingredients are the chemicals that are actually effective against the pest. The rest of the product is composed of an inert ingredient(s). The percentage of total inert ingredient(s) (which can range from 0 to 99.9%) is listed on the product label.

Why is an inert ingredient(s) included in a product?

Inert ingredients are added to products for a variety of reasons, including the following:
- To improve product performance.
- To make them easier to apply.
- To help the pesticide dissolve in water.
- To help the pesticide spread over the surface or stick to leaves and soil.
- To help move the pesticide into insects' bodies.
- To stabilize the product for longer shelf-life *(1)*.

Why is the inert ingredient name not listed on the product label?

- Unless an inert ingredient is determined to be highly toxic, it is not required by law to be identified by name or percentage on the label, but the total percentage of such ingredients must be declared (*2*).
- Pesticide companies keep the inert ingredient(s) secret to be competitive in the marketplace. The inert ingredient(s) is considered confidential business information or a trade secret (*3*).
- The EPA has formed the *Inert Disclosure Stakeholder Workgroup* to advise the Pesticide Program Dialogue Committee on ways of making information about inert ingredients more available to the public (*4*).

Are inert ingredients toxic?

- Inert ingredients can range in toxicity from extremely toxic to practically non-toxic (*5*). Each inert ingredient has its own level of toxicity. See **Dose response** box.
- Some inert ingredients are toxic when swallowed or inhaled; some are toxic when absorbed through the skin.
- An inert ingredient may irritate or otherwise cause harm to skin or eyes.
- The U. S. Environmental Protection Agency (EPA) has established several inert ingredient lists based on the relative toxicity of the chemical substance. (*5*).

Dose response. Effects of inert ingredients on human health and the environment depend on how much chemical is present, the length and frequency of exposure, and route of exposure. Effects also depend on the health of a person and/or certain environmental factors.

What are the EPA lists of inert ingredients?

- The EPA has compiled a list of all inert ingredients allowed in pesticide products (*5, 6*).
- The list was broken down in 1987 into four lists based on the overall toxicity hazard to humans or the environment. See **Inert Ingredient Lists** box (*6*).
- Six chemicals are listed as inert ingredients of highest health concern (List 1); one example is formaldehyde.
- Examples of inert ingredients of minimal health concern (List 4) are lard, sawdust, and oyster shells (*5*).

Inert Ingredient Lists:

- List 1- Inert ingredients of toxicological concern.
- List 2- Potentially toxic inert ingredients/high priority for testing.
- List 3- Inerts of unknown toxicity.
- List 4- Inerts of minimal concern.

EXAMPLES OF INERT INGREDIENTS AND CATEGORY LISTING

Category list	Substance	CAS No.	Category List	Substance	CAS No.
List 4	Carnauba wax	8015-86-9	List 2	o-Cresol	95-48-7
	Diatomaceous earth	61790-53-2		Fuel oil, No.2	68476-30-2
	Ferric oxide	1309-37-1		Isopropylphenol	618-45-1
	Limonene	5989-27-5		Methyl isobutyl ketone	108-10-1
	Magnesium sulfate	7487-88-9		Nitroethane	79-24-3
	Polypropylene glycol	25322-69-4		Parafins	64771-72-8
	Potassium salts of fatty acids (C12-C20)	69669-25-6		Propylene glycol monobutyl ether	29387-86-8
	Vermiculite	1318-00-9		Toluene	108-88-3
List 3	Agar	9002-18-0		Xylene	1330-20-7
	Avacado oil	8024-32-6	List 1	Dioctyl phthalate	117-84-0
	Cod Oil	97553-00-9		Formaldehyde	50-00-0
	Ethoxylated lanolin	61790-81-6		Hydroquinone	123-31-9
	Menthol	1490-04-6		Isophorone	78-59-1
	Pitch	61789-60-4		Nonylphenol	25154-52-3
	Sodium nitrite	7632-00-0		Phenol	108-95-2
	Turpentine	9005-90-7		Rhodamine B	81-88-9

How can I find out what the inert ingredient(s) is in a pesticide product?

- Pesticide manufacturers sometimes release the identity of the inert ingredient(s) not listed on a product. Most manufacturers have product information telephone numbers. An inert ingredient(s) is sometimes listed on material safety data sheets (MSDS) published by the manufacturer.
- Citizens can submit Freedom of Information Act (FOIA) requests to ask for information about inert ingredients from the EPA. A fees for search, review and copy services may be assessed. Visit the web site "Freedom of Information Act" (FOIA) home page at http://www.epa.gov/pesticides/foia to learn how to submit a FOIA request. (7).
- Confidential Business Information (CBI) requests may initially be denied due to confidentiality considerations. EPA will contact the affected business in writing to ascertain the validity of the CBI claims. This initial denial of the request is procedural in nature and does not constitute final action on the request (7).
- Pesticide companies will often disclose the inert ingredient(s) in their product to medical professionals for treatment related to pesticide poisonings. The medical staff may be asked to sign a statement that they will keep the information secret.

How can I find out the toxicity of the inert ingredient?

- EPA requires manufacturers to identify an inert ingredient of highest concern (List 1) on the label *(1)*.
- The overall toxicity of the pesticide product, which takes into account the toxicity of the inert ingredients and the active ingredient combined, is listed on the label in the form of a SIGNAL WORD. For example, pesticide products that are low in overall toxicity would display a signal word of CAUTION on the label. Pesticide products that are moderately or highly toxic would display WARNING or DANGER signal words, respectively. See **Pesticide Label** box
- See **Toxicity Category** box below for further information (*8*).

LD50/LC50: A common measure of acute toxicity is the lethal dose (LD50) or lethal concentration (LC50) that causes death (resulting from a single or limited exposure) in 50 percent of the treated animals. LD50 is generally expressed as the dose in milligrams (mg) of chemical per kilogram (kg) of body weight. LC50 is often expressed as mg of chemical per volume (e.g., liter (L)) of medium (i.e., air or water) the organism is exposed to. Chemicals are considered highly toxic when the LD50/LC50 is small and practically non-toxic when the value is large. However, the LD50/LC50 does not reflect any effects from long-term exposure (i.e., cancer, birth defects, or reproductive toxicity) that may occur at levels below those that cause death.

Toxicity Category (*Signal Word*)

Exposure	High Toxicity (*Danger*)	Moderate Toxicity (*Warning*)	Low Toxicity (*Caution*)	Very Low Toxicity (*Caution*)
Oral LD50	Less than 50 mg/kg	50 - 500 mg/kg	500 - 5000 mg/kg	Greater than 5000 mg/kg
Dermal LD50	Less than 200 mg/kg	200 - 2000 mg/kg	2000 - 5000 mg/kg	Greater than 5000 mg/kg
Inhalation LC50	Less than 0.05 mg/l	0.05 - 0.5 mg/l	0.5 - 2 mg/l	Greater than 2 mg/l
Eye Effects	Corrosive	Irritation persisting for 7 days	Irritation reversible within 7 days	Minimal effects, gone within 24 hrs
Skin Effects	Corrosive	Severe irritation at 72 hours	Moderate irritation at 72 hours	Mild or slight irritation

What else should I know about inert ingredients?

- Scientists are continually evaluating the potential risks of certain inert ingredients in pesticide products.
- The EPA encourages pesticide manufacturers to use less toxic inert ingredients in their products (*2*).
- The EPA does not allow the use of several chemicals as inert ingredients in pesticide products (*9*).
- The EPA is encouraging pesticide manufacturers to use the term "other" instead of "inert" ingredients. They believe that this term is less confusing to the consumer and does not imply that these chemicals are risk free (*10*).

Date reviewed: December 2000

For more information contact: NPTN
Oregon State University, 333 Weniger Hall, Corvallis, Oregon 97331-6502.
Phone: 1-800-858-7378 Fax: 1-541-737-0761 Email: nptn@ace.orst.edu
NPTN at http://nptn.orst.edu/ EXTOXNET at http://ace.orst.edu/info/extoxnet/

References

(1) *Label Review Manual*; EPA 737-B-96-001; U.S. Environmental Protection Agency, National Technical Information Service: Springfield, VA, 1996, pp 6-1 to 6-15.
(2) U.S. Environmental Protection Agency. 1997. Pesticide Regulation (PR) Notice 97-6. http://www.epa.gov/ngispgm3/iris/subst/0142.htm (accessed August 2000).
(3) Legal Information Institute. Protection of trade secrets and other information (U.S. Code Title 7, Chapter 6, Sub-chapter II, Section 136h). http://www4.law.cornell.edu/uscode/unframed/7/136h.html (accessed September 2000).
(4) U.S. Environmental Protection Agency. 2000. First Public Meeting of the Inert Disclosure Stakeholder Workgroup. www.epa.gov/oppfead1/cb/csb_page/updates/inert.htm (accessed November 2000).
(5) U.S. Environmental Protection Agency. 1999. Lists of Other (Inert) Pesticide Ingredients. http://www.epa.gov/opprd001/inerts/lists.html (accessed August 2000).
(6) U.S. Environmental Protection Agency. 1987. Inert Ingredients In Pesticide Products; Policy Statement (52 FR 13305). http://www.epa.gov/opprd001/inerts/fr52.htm (accessed September 2000).
(7) U.S. Environmental Protection Agency. 2000. Freedom of Information Act (FOIA) Home Page. http://www.epa.gov/pesticides/foia (accessed November 2000).
(8) U.S. Environmental Protection Agency. 1996. Label Review Manual Chapter 8 : Precautionary Labeling. http://www.epa.gov/oppfead1/labeling/lrm/chap-08.htm (accessed September 2000).
(9) Inert Ingredients No Longer Used in Pesticide Products. *Fed. Regist.* 06/24, **1998,** Vol. 63 (121), pp 34384-34390.
(10) U.S. Environmental Protection Agency. 1997. Questions & Answers: Consumer Labeling Initiative. http://www.epa.gov/opptintr/labeling/v1q39loi.pdf (accessed April 2000).